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THE LINNAEITE GROUP OF COBALT-NICKEL- IRON-COPPER SULFIDES

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The linnaeite group of sulfides as given by various mineralogists includes several different minerals. Dana¹ includes linnaeite (siegenite), daubréelite, cubanite, and carrollite. He does not include polydymite. In the 1932 edition of Dana-Ford's *Textbook of Mineralogy* (pp. 430-431), sychnodymite is included with linnaeite, and polydymite is called "nickel-linnaeite." Violarite and badenite are also placed in this group. It may be possible that later studies will place badenite, $(\text{Co}, \text{Ni}, \text{Fe})_3 (\text{As}, \text{Bi})_4?$, and daubréelite, $\text{FeS} \cdot \text{Cr}_2\text{S}_3$, definitely in this group, but cubanite, $\text{Cu}_2\text{S} \cdot \text{Fe}_4\text{S}_5$, does not belong here as it is orthorhombic in crystallization. Doelter² uses the term "Polydymite-Carrollite-group" for the linnaeite minerals. Linnaeite (siegenite), polydymite, carrollite, and sychnodymite are included in his list. Daubréelite is placed in this group, but not because Doelter is satisfied that it belongs there; he merely follows the grouping of other mineralogists. Hintze³ includes carrollite, daubréelite, linnaeite (siegenite), sychnodymite, polydymite, and also hauchecornite, which, however, as it crystallizes in the tetragonal system is not a member of this group. Violarite, $(\text{Ni}, \text{Fe})_3\text{S}_4$, was described and named by Lindgren⁴ (who without an analysis tentatively assigned it the formula, NiS_2), and is undoubtedly a member of the linnaeite group. The formula, $(\text{Ni}, \text{Fe})_3\text{S}_4$, was determined by Short and Shannon (Ref. 31) in 1930. The following minerals are included in this discussion: linnaeite, carrollite, sychnodymite, siegenite, violarite, and polydymite. Daubréelite, the iron-chromium sulfide, included in the linnaeite group by some mineralogists, will not be discussed

¹ Dana, E. S., *System of Mineralogy*, 6th Edit., 1909, p. 78.

² Doelter, C., *Handbuch der Mineralchemie*, Band iv, pt. I, 1926, pp. 645-657.

³ Hintze, Carl, *Handbuch der Mineralogie*, Band I, pt. I, 1904, pp. 957-968.

⁴ Lindgren, W., *Econ. Geol.*, vol. 19, 1924, p. 309.

in this article because it has not been definitely shown that it belongs in the isometric system. The proximity in the periodic table of chromium to cobalt, nickel, copper, and iron would favor the possibility that daubréelite would be found to be a member of the group; but *x*-ray studies are needed to determine its structure.

The marked range in composition shown by the minerals within this group was brought to the writer's attention while he was comparing a new analysis of siegenite with the earlier analyses of the mineral. The new analysis was made in 1932 by Lix⁵ of a siegenite from the well known Mine La Motte locality in Madison County, Missouri. The analysis was made on crystals carefully selected so as to be practically free from chalcopyrite, the commonest and most intimately associated mineral. This analysis is number 28 in the list given below. Mr. Lix after studying a group of analyses placed his new one among those of the siegenites. He concluded that the cobalt, nickel, iron, and copper determined in his analysis were isomorphous, a conclusion in accord with that made by some others who have studied the group. This study has been made by the writer in an effort to determine whether these four elements are actually isomorphous, and whether dividing lines actually exist between the minerals within the group.

Each mineral of the group is fairly well represented by analyses, which, however, as would be expected, vary in their completeness and accuracy. After eliminating those of manifestly little value, there remained 37 analyses (one of them a recalculated analysis). These are tabulated in the order of their decreasing cobalt content, and under their common mineral names in the following table:

LINNÆITE (Haidinger, 1845)

Number	Locality	S	Co	Ni	Fe	Cu	R ₃ S ₄ ratio
1	Müsen	42.25	53.35	—	2.30	0.97	R ₃ S _{4.09}
2	Carroll Co., Md.	41.70	48.70	4.75	2.36	2.40	R ₃ S _{3.96}
3	Sykesville, Md.	43.56	48.63	Trace	3.55	4.43	R ₃ S _{4.27}
4	Bastnäs	41.83	44.92	0.19	4.19	8.22	R ₃ S _{4.04}
5	Gladhammar	41.43	40.71	7.35	1.30	8.79	R ₃ S _{4.19}
6	Müsen	42.76	39.35	14.09	1.06	1.61	R ₃ S _{4.19}
7	Gladhammar	42.19	39.33	12.33	4.29	2.28	R ₃ S _{3.96}

⁵ Lix, Henry W., The Composition and Occurrence of Siegenite. M.A. Thesis, *Univ. of Mo.*, 1932.

Num- ber	Locality	S	Co	Ni	Fe	Cu	R ₃ S ₄ ratio
CARROLLITE (Faber, 1852)							
8	Carroll Co., Md.	41.34	42.42	Trace	0.28	15.43	R ₃ S ₄
9	Carroll Co., Md.	41.71	38.70	1.70	0.46	17.55	R ₃ S _{4.03}
10	Carroll Co., Md.	40.94	38.21	1.54	1.55	17.79	R ₃ S _{3.97}
11	Carroll Co., Md.	40.99	37.65	1.54	1.40	19.18	R ₃ S _{3.87}
12	Kantanga	39.40	37.50	Trace	—	19.60	R ₃ S _{3.90}
13	Gladhammar	39.89	37.29	0.78	2.54	19.33	R ₃ S _{3.80}
14	Carroll Co., Md.	41.93	37.25	1.54	1.26	17.48	R ₃ S _{4.11}
15	Carroll Co., Md.	41.89	36.08	7.65	2.25	9.98	R ₃ S _{4.18}
16	Gladhammar	39.47	35.30	1.76	2.33	20.42	R ₃ S _{3.72}
17	Gladhammar	40.74	35.15	7.01	2.18	13.90	R ₃ S _{3.90}
SYCHNODYMITE (Laspeyres, 1891)							
18	Siegen I.	40.64	35.79	3.66	0.93	18.98	R ₃ S _{3.65}
19	Siegen I.	40.33	35.64	5.74	0.82	17.23	R ₃ S _{3.83}
20	Siegen I.	39.28	26.80	5.70	3.86	23.46	R ₃ S _{3.72}
SIEGENITE (Dana, 1850)							
21	Müsen	42.63	26.08	31.18	0.62		R ₃ S _{4.03}
22	Mineral Hill, Md.	39.70	25.69	29.56	1.96	2.23	R ₃ S _{3.70}
23	Müsen	40.40	23.39	27.78	2.98		R ₃ S _{4.04}
24	Müsen	41.98	22.09	33.64	2.29		R ₃ S _{3.98}
25	Mine La Motte, Mo.	42.13	21.67	31.00	3.42		R ₃ S _{4.12}
26	Mine La Motte, Mo.	41.54	21.34	30.53	3.37	Trace	R ₃ S _{4.17}
27	Müsen	40.61	20.44	38.16	0.57		R ₃ S _{3.77}
28	Mine La Motte, Mo.	42.43	20.36	31.24	3.22	3.16	R ₃ S _{4.05}
29	Hilgenroth	37.66	15.47	26.55	9.02	0.57	R ₃ S _{3.92}
30	Müsen	42.30	11.00	42.64	4.69		R ₃ S ₄
VIOLARITE (Lindgren, 1924)							
31	Julian, Calif.	42.17	2.50	33.94	19.33	1.05	
32	Sudbury, Ont.	41.68	1.05	38.68	17.01	1.12	
33	Sudbury, Ont.	41.35		43.18	15.47		
POLYDYMITE (Laspeyres, 1876)							
34	Grüneau Mine, Siegen	41.08	3.95	49.24	4.76		R ₃ S _{3.91}
35	Grüneau Mine, Siegen	39.20	0.53	13.00	4.12		R ₃ S _{4.03}
36	Grüneau Mine, Siegen	40.27	0.61	53.51	3.84		R ₃ S _{3.92}
37	Grüneau Mine, Siegen	41.09	0.63	54.30	3.98		R ₃ S _{3.83}

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 14. Smith, L., and Brush, G. J., same as No. 9.
 15. Shannon, Earl V., same as No. 2.
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 17. Johannson, K., same as No. 5.
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For name see Lindgren, W., *Econ. Geol.*, vol. 19 (1924), p. 318.
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 35. Laspeyres, H., *Jour. Prak. Chem.*, vol. 14 (1876), p. 397.
 36. Laspeyres, H., *Jour. Prak. Chem.*, vol. 14 (1876), p. 397.
 37. Laspeyres, H., *Jour. Prak. Chem.*, vol. 14 (1876), p. 397.
- Most of the above analyses are more readily accessible in one of the following:
- Doelter, C., *Handbuch der Mineral chemie*, vol. 4, pt. 1 (1926), pp. 645-657, 702 (violarite).
- Hintze, C., *Handbuch der Mineralogie*, vol. 1, pt. 1 (1904), pp. 957-966.
- Dana, E. S., *System of Mineralogy*, 6th Ed. (1909), pp. 75-79.
- Mineralogical Abstracts of the Mineralogical Society of Great Britain.

For the most part, the analyses of the minerals are fairly similar, allowing, of course, for the steady decrease in the content of the cobalt and its replacement by the other three metals: nickel, iron, and copper. The quantity of these three metals that replaces the cobalt varies rather widely, and in the past (with some exceptions) they have been regarded as impurities. The various formulae (in which $R = \text{Co, Ni, Fe, Cu}$) suggested for each of the different minerals are as follows:

linnaeite— R_3S_4 , $\text{CoS} \cdot \text{Co}_2\text{S}_3$, or CoCo_2S_4 .

carrollite— R_3S_4 , $\text{CuS} \cdot \text{Co}_2\text{S}_3$, or CuCo_2S_4 .

synchodumite— R_3S_4 , R_4S_5 , usually $(\text{Co, Cu, Ni})_4\text{S}_5$.

siegenite— R_3S_4 , usually $(\text{Ni, Co})_3\text{S}_4$.

violarite— R_3S_4 , usually $(\text{Ni, Fe})_3\text{S}_4$.

polydymite— R_3S_4 , also Ni_4S_5 , $(\text{Ni, Fe, Co})_4\text{S}_5$.

These various formulae were tested by recalculating all the analyses for each mineral, and it was found that the formula R_3S_4 was the best. However, x -ray studies of the members of the group (save violarite) show that they have the typical spinel structure; therefore, their formula should be written $\text{R}''\text{R}_2'''\text{S}_4$ ($\text{R}'' = \text{divalent Co, Ni, Cu, Fe}$; and $\text{R}''' = \text{trivalent Co, Ni, Fe}$). The simpler formula might be used, but it seems better to use the one indicating the molecular structure of the mineral as revealed by x -rays. In the above table, the R_3S_4 was used because it indicates briefly how closely each analysis approaches the exact 3:4 ratio. It should be noted that only Co, Ni, and Fe are assigned places in the trivalent group. This is in keeping with the chemistry of these elements as the compound R_3S_4 is known for all of them. No similar salt exists for copper; therefore, when it occurs in the linnaeite group it appears only with the R'' elements.

An inspection of the table reveals five well defined groups of analyses, with a doubtful sixth if synchodumite is recognized as a separate mineral because of its nickel content. At one end are the dominantly cobalt analyses representing linnaeite, and at the other end the nickel-rich analyses representing polydymite. The copper-rich analyses without nickel are grouped as "carrollite"; for those having some nickel, the name "synchodumite" has been used. The latter name would seem to be of doubtful value even as a variety name, as the three analyses of it closely resemble those of carrollite, with which it probably belongs. Where both nickel and cobalt are present in somewhat similar amounts, the

name "siegenite" is used, and as the cobalt decreases and iron appears with the nickel the mineral is called "violarite." It is conceivable that there should be a mineral having the composition Fe_3S_4 , corresponding to the similar salts of cobalt and nickel, but none is known.

Figure 1 presents graphically, and in the same sequence, the composition of the analyses given in the table. The curves for each

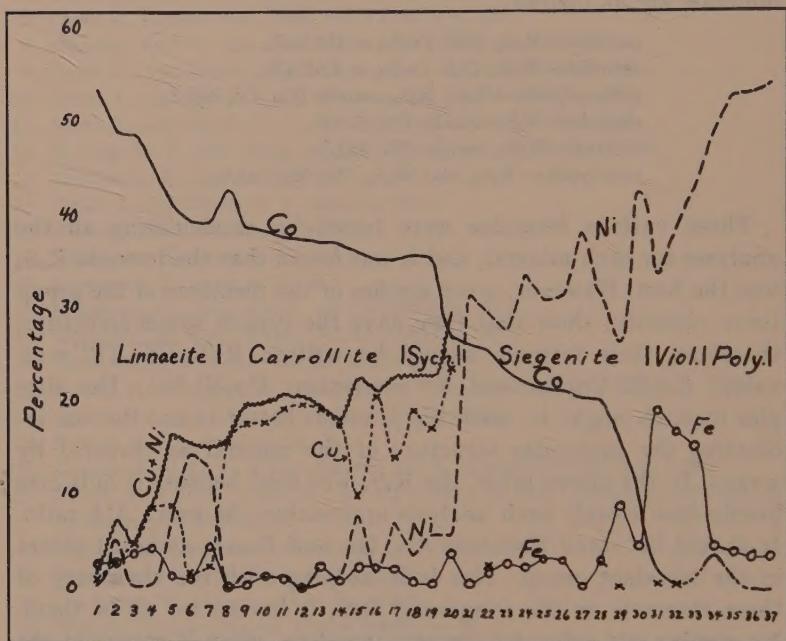


FIG. 1. Curves showing the composition of the linnaeite group by elements. Numbers are those of the analyses in the table.

element (assuming that cobalt is the dominant element) bring out the relationship of the copper to the cobalt and nickel, and the nickel to the cobalt and iron. That the copper is isomorphous with the cobalt is shown by the increase in its content as the cobalt content decreases, the two curves approaching each other steadily. Also, that some nickel replaces the copper is shown by the increase in the nickel content with the copper-content decrease. Where the total amount of copper and nickel are plotted together, as in figure 1, the character of the resulting curve matches nicely with

the changes in the cobalt curve. Where nickel entirely replaces copper and equals or exceeds cobalt in amount, as it does in siegenite, the nickel curve mounts steadily as the cobalt content decreases. Near the end of the series, iron enters and replaces a part of the nickel (Fig. 2), forming violarite; but at the end the iron has decreased until only nickel is left. Cobalt and iron appear to have little in common, as iron does not appear in any quantity

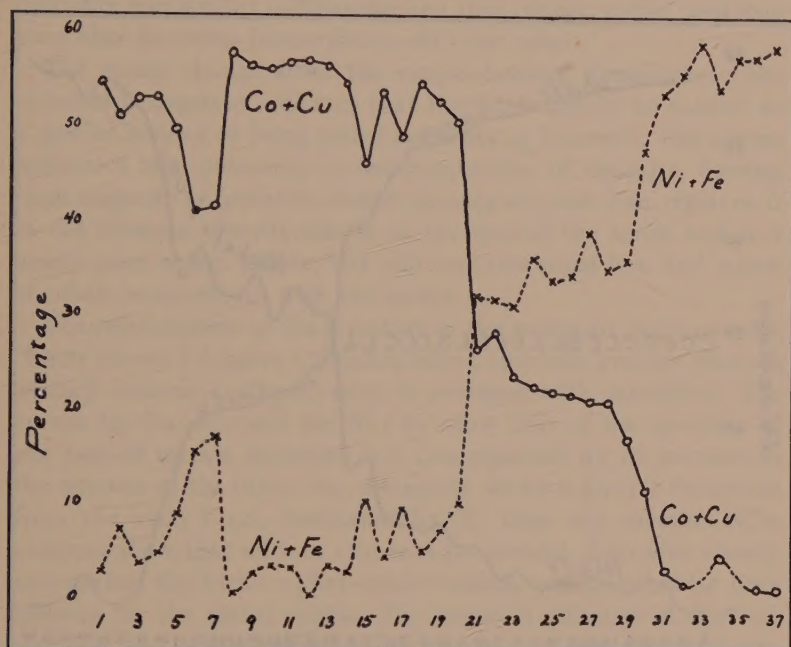


FIG. 2. The paired isomorphous elements: Co+Cu and Ni+Fe, of figure 1.
Note the strong similarity of the two curves throughout.

until the cobalt content has fallen below 10 per cent. The appearance of the iron in the nickel-rich members is in perfect keeping with the common association of these two elements in many other minerals. The copper undoubtedly takes the place of the cobalt in the R'' position in the spinel formula. Cobalt is both divalent and trivalent, hence in linnaeite it appears in both forms; but, as the copper enters, it displaces the cobalt as the divalent element. As both nickel and iron are also divalent, varying amounts of both these elements may replace some copper and cobalt. A check of

the percentage of copper in carrollite and sychnodymite showed that in only one analysis did the copper content exceed the amount of copper (i.e., 20.52 per cent) that could replace the divalent elements. Johansson (Ref. 5) suggests 15 per cent as the maximum for Cu in linnaeite, and regards carrollite as a mixture (a needless and erroneous deduction). Further evidence that the copper is isomorphous with the cobalt is shown in figure 2, in which total

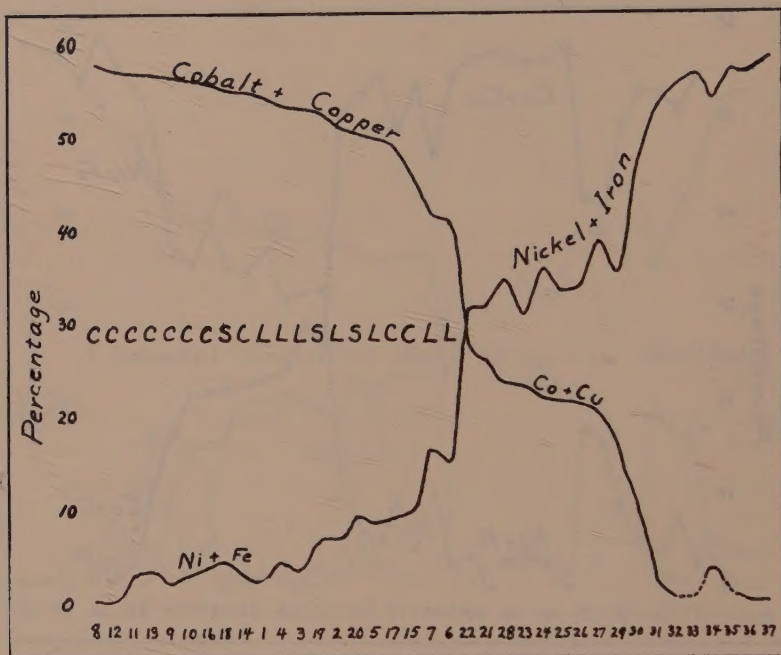


FIG. 3. Curves based upon decreasing Co+Cu content. Note the positions of linnaeite (L) and sychnodymite (S) with reference to the carrollite (C). The Co in polydymite No. 34 is ignored in the arrangement.

cobalt and copper are plotted together as are total nickel and iron. Whenever the first two decrease, the last two increase. As the cobalt content controlled the distribution in the plotting, the matched irregularities in the two curves suggested that the order of plotting in the curves should be according to the sum of the cobalt and copper. This was done for all the analyses, and a curve constructed (figure 3) according to the decrease in cobalt and copper content. This resulted in mixing the position of the first

20 minerals (the first linnaeite analysis appears in position number 11); in short, cobalt and copper are the determining factors in the composition of linnaeite, carrollite, and sychnodymite, which strongly confirms the view that the two elements are isomorphous. The formula would then conform to that of the spinel group and should be written $(\text{Cu},\text{Co})\text{Co}_2\text{S}_4$. This is in keeping with the chemical studies of Shannon,⁶ who showed that carrollite was similar to linnaeite and that copper, nickel, and iron were also doubtless isomorphous with the cobalt.

The sharp change from the copper-bearing linnaeites to the nickel-rich siegenite indicates that the latter should be ranked as a species instead of being called a variety of linnaeite. The curves indicate a fair uniformity in the composition of siegenite. Passing from siegenite to violarite, cobalt disappears and iron replaces it in the formula. Polydymite is at the end of the series and is a nearly pure nickel sulfide, but still contains some iron and traces of cobalt isomorphous with the nickel.

The relationships of the members of the group are perhaps more clearly shown by figure 4 which is based upon the average analysis of each mineral (sychnodymite is averaged with carrollite). The curves for $\text{Co}+\text{Cu}$ and for $\text{Ni}+\text{Fe}$ show that as the quantity of one pair of metals decreases it is accompanied by an increase in the amount of the other two. Linnaeite shows a greater departure from the ideal Co_3S_4 (indicated by X) than any member. The analyses show that all four elements are present. Carrollite closely approaches the ideal copper-cobalt sulfide, and polydymite does likewise for the nickel sulfide. The chemical affinities of the four elements and the dominant isomorphous pairs are clearly shown by the curves.

This interpretation of the members of the linnaeite group as an example of an isomorphous series of the four elements finds further support in the x-ray studies which have been made of them. The statement is made in the 1932 edition of Dana-Ford's *Textbook of Mineralogy* (page 430) that "x-ray study shows practically identical structure in linnaeite, polydymite and sychnodymite. Structure is face-centered cube." Studies made by de Jong and Hoog⁷ show that carrollite has the same spinel structure as

⁶ Shannon, Earl V., The Identity of Carrollite with Linnaeite, *Am. Jour. Sc.*, vol. 211, 1926, p. 488.

⁷ de Jong, W. F., and Hoog, A., *Zeits. Krist.*, vol. 66, 1927, pp. 168-71.

linnaeite and sychnodymite, which definitely correlates it with the other members of the group. Holgersson⁸ definitely added siegenite to the group by his *x*-ray studies in 1929. Thus, the only mineral of the group not definitely shown by *x*-ray analysis to possess the

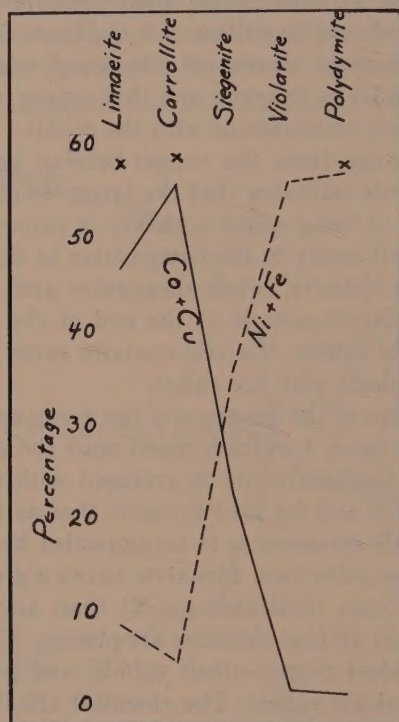


FIG. 4. Average analysis of the five major members of the linnaeite group (sychnodymite is averaged with carrollite, where it belongs).

spinel structure is violarite, and its composition strongly indicates its possessing it.

The atomic radii of these four elements are so close that isomorphism should be expected. According to Neuburger⁹ they are, in Ångström units, Fe=1.259, Co=1.256, Ni=1.243, Cu=1.275.

⁸ Holgersson, Sven, *Chem. Zentr.*, vol. 1, 1929, pp. 372-3.

⁹ Neuburger, M. C., Gitterkonstanten für 1931, *Zeits. Krist.*, vol. 80, 1931, pp. 126-127.

Wyckoff, R. W. G. has similar data in the second edition of his *The Structure of Crystals*, 1931, pp. 192-193.

These values would make it possible for them to replace each other within a crystalline structure. The analyses show, however, that such replacement has been restricted dominantly to certain pairs, with copper and iron the subordinate elements. The door was open for an extremely variable group of replacements, which, for the most part, were restricted to these paired groups, indicating that either the composition of the solution (in which one or two elements predominated) was a controlling factor, or that isomorphism is a last resort in mineral formation. The fact that the mineral members of this group occur alone favors the first interpretation.

However,¹⁰ recent studies of the spinel structure by Barth and Posnjak¹¹ have revealed the fact that there are two structural arrangements within the true spinel group, one with fixed positions for the ions and the other with variable positions. In the latter (for which Barth and Posnjak suggest the term, "cells with variate atom equipoints"), "different atoms may partly replace one another in structurally equivalent positions of a crystal." The fixed spinel structure corresponds to $XY_2S_4(R''R_2'''S_4)$ in the linnaeite group, and $YXYS_4$ is the arrangement in the variate atom equipoint group. As noted above, the study of the available chemical analyses of the members of this group favored the formula XY_2S_4 as being best suited to the chemical relationships of the four elements (Fe, Co, Ni, Cu). The study showed, also, that the atomic radii would permit any element to isomorphously replace another. It is, of course, perfectly possible to apply the type formula of the variate spinel group to this group of sulfides but there does not appear to be any reason, at present, for doing so. If *x*-ray studies showed that violarite, for example, belonged in the variate group, its formula would be written $NiFeNiS_4$ instead of $FeNi_2S_4$. Nothing seems to be gained by this change. The linnaeite group would seem to offer an excellent opportunity to make an *x*-ray study of the sulfide members of the spinel group, and to determine, if possible, whether the two spinel groups are

¹⁰ The writer is indebted to Dr. George Tunell of the Geophysical Laboratory for calling his attention to the new interpretation of the spinel structure and for suggestions as to its application to the linnaeite group.

¹¹ Barth, Tom. F. W., and Posnjak, E., The Spinel Structure: An Example of Variate Atom Equipoints: *Jour. Wash. Acad. Science*, vol. 21, 1931, pp. 255-258.

Barth, Tom. F. W., and Posnjak, E., Spinel Structures: With and Without Variate Atom Equipoints: *Zeits. Krist. (A)* Band 82, 1932, pp. 325-341.

present. Dr. Tunell¹² expressed himself regarding such a study as follows: "On looking up the scattering powers of copper, nickel, and cobalt I find that they are so nearly alike that it will not be possible to discriminate the two structure types in compounds of these elements."

Dr. Wyckoff of the Rockefeller Institute for Medical Research has also expressed the opinion¹³ that the "distinction (of the two classes of spinel structures) would have no bearing on the structure of linnaeite considered basically as Co_3S_4 ." These two opinions indicate that as far as the minerals included in this study are concerned, the fixed spinel type may be adopted as their structural type.

SUMMARY

This study of the chemical composition of the best analyses available for the various members of the linnaeite group has furnished, it is believed, evidence that all members of the group should be represented by the general formula $\text{R}''\text{R}_2'''\text{S}_4$. The four elements Co, Ni, Fe, and Cu are isomorphous, but copper, only, as a divalent element. The atomic radii of the four elements are so nearly identical that such isomorphism is easily possible. The name "Carrollite" (CuCo_2S_4) is preferred for those minerals rich in copper, and "Sychnodymite" might very well be dropped, even as a variety name. X-ray studies of all the members, except violarite, show that they have the spinel structure type, and give further proof that the several minerals in the group: linnaeite, carrollite (sychnodymite), siegenite, probably violarite, and polydymite have the same type formula. It appears doubtful whether further x-ray studies would contribute any more information regarding the structures of the group.

¹² In a letter to the writer.

¹³ In a letter to the writer.

AGE AND DISTRIBUTION OF PEGMATITES

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AGE¹

INTRODUCTION

Pegmatites have been formed during periods of intrusive igneous activity from the pre-Cambrian to the present. A *detailed* age classification of such deposits is impossible of compilation at present. Most pegmatites occur in regions of crystalline rock where age determinations from field observations are usually approximations at best. However, important progress has been made during the last decade in determining the age of pegmatites and other mineral bodies containing radioactive minerals by determining the ratios between lead and uranium and thorium.² Analyses have shown that the pegmatites in the great pre-Cambrian shield areas, many of which are undatable from geological evidence, are themselves pre-Cambrian in age. Most of the analytical work to date in rocks younger than the pre-Cambrian has been for the purpose of building up a time scale through obtaining specimens from rock bodies which were already fairly well placed in the geologic column by field observations. In the future more use can be made of this method to determine the age of pegmatites and other radioactive mineral-bearing deposits which are impossible of dating by field observation. This has already been done by Foye³ in New England.

THE PRE-CAMBRIAN PEGMATITES

Pegmatites are abundant in the pre-Cambrian areas of the Laurentian Shield of northeastern North America, the Fennoscandian Shield in northwestern Europe (including Scotland), and in the Gondwanaland belt of South America, Africa, India, and Australia. In addition many smaller areas of pre-Cambrian rock

¹ The writer gratefully acknowledges helpful criticism given during the preparation of this chapter by A. C. Lane and J. P. Marble.

² Holmes, Arthur, Radioactivity and geological time: *Nat. Research Council, The Age of the Earth*, pp. 124-459, 1931. Lane, Alfred C., *Nat. Research Council, Rept. of the Committee on the Measurement of Geological Time*, 1933.

³ Foye, W. G., and Lane, A. C., Correlations by radioactive minerals in the metamorphic rocks of southern New England: *Am. Jour. Sci.* (5) vol. 28, pp. 127-138, 1934.

contain pegmatites. Examples of the latter in North America are the belt of pre-Cambrian rocks in the Appalachian Mountain region, a large number of districts in the Rocky Mountain area, and the inner gorge of the Grand Canyon of Arizona.

Simple pegmatites (those in which no hydrothermal replacement has taken place⁴) are extremely common in the pre-Cambrian terrane. Many of these are of the lit-par-lit type. Some of the simple pegmatites are sufficiently large to be exploitable for feldspar or mica or other minerals. Complex pegmatites were also formed during pre-Cambrian time. Examples are the lithium pegmatites of Western Australia and the Rocky Mountain belt (including the Black Hills) of North America; the rare earth pegmatites⁵ of Llano County (Texas), Minas Geraes (Brazil), Ytterby (Sweden), Tanganyika, and India; and the beryl pegmatites of Brazil and South Africa.

PALEOZOIC PEGMATITES

Pegmatites of Paleozoic age are found wherever the Paleozoic era was marked by intrusive igneous activity. One of the best regions illustrating this is New England and the Paleozoic Appalachians to the southwest. According to Bastin,⁶ the granites of Maine were intruded in Late Silurian or Devonian time, and the pegmatites are also probably of that age. The Strickland pegmatite at Portland, Connecticut, the near-by Hale deposit (Glastonbury), and the Blueberry Mountain pegmatite at Woburn, Massachusetts, are Devonian in age.⁷ The famous Bedford pegmatite in Westchester County, New York, intrudes the Ordovician Hudson schist.⁸ The ages of both this and the Branchville, Connecticut, phosphate pegmatite have been determined by the lead-uranium ratio to be 380 million years, which corresponds to the Late Ordovician (Taconic revolution).⁹ Virginia and the Carolinas

⁴ Landes, Kenneth K., Origin and classification of pegmatites: *Am. Mineral.* vol. 18, pp. 33-56, and 95-103, 1933.

⁵ Holmes, Arthur, Radioactivity and geological time: *Nat. Research Council, The Age of the Earth*, pp. 276 et. seq., 1931.

⁶ Bastin, Edson S., Geology of the pegmatites and associated rocks of Maine: *U. S. Geol. Survey, Bull.* 445, p. 15, 1911.

⁷ Lane, Alfred C., *Rept. of the Committee on the Measurement of Geological Time: Nat. Research Council*, pp. 11-13, 1933.

⁸ Bastin, Edson S., Feldspar and quartz deposits of southeastern New York: *U. S. Geol. Survey, Bull.* 315, pp. 394-395, 1906.

contain pegmatites both in the pre-Cambrian and in the Late Paleozoic.¹⁰ Many of the pegmatites in the New England-Appalachian belt are complex, exhibiting lithium, boron, phosphate and other phases. Paleozoic alkaline syenite pegmatites occur on Mount Royal, Montreal.

Intrusions of pegmatite accompanied Paleozoic ore deposition in widely scattered parts of the globe. Tungsten-bearing pegmatites in England are post-Silurian in age.¹¹ Both tin and tungsten minerals occur in pegmatitic quartz veins accompanying the Paleozoic granites of western Spain.¹² Tin-bearing pegmatite dikes in eastern Victoria cut the Silurian metamorphic series.¹³ Pegmatites associated with the ore deposits of the New England area of New South Wales are related to Carboniferous and Permo-Carboniferous granite. Ore-bearing pegmatites accompany Devonian granite in northern Tasmania.¹⁴ A Paleozoic age is assigned by Holmes¹⁵ to the rare earth pegmatites of Langesundfjord, Southern Norway, and Miask, Urals.

MESOZOIC PEGMATITES

The great batholiths which were intruded in the latter part of the Mesozoic in the Cordilleran region of western North America were accompanied by pegmatites. Granitic pegmatites occurring in British Columbia are referred to the Lower Cretaceous.¹⁶ Peg-

⁹ Agar, Wm. M., The pegmatites of Bedford, New York: *Sixteenth International Geological Congress, Guidebook 9*, p. 126, 1933.

¹⁰ Pegau, A. A., The pegmatites of the Amelia, Goochland, and Ridgeway areas, Virginia: *Am. Jour. Sci.* (5), vol. 17, pp. 543-547, 1929. Lonsdale, John T., Geology of the gold-pyrite belt of the northeast piedmont, Virginia: *Virginia Geol. Survey, Bull.* 30, pp. 1-110, 1927. Keith, Arthur, The Gaffney-Kings Mountain Folio, South and North Carolina: *U. S. Geol. Survey, Geol. Folio* 222, 1931.

¹¹ Finlayson, A. M., Ore-bearing pegmatites of Carrock Fells: *Geol. Mag., n.s.*, vol. 7, pp. 19-28, 1910.

¹² Krusch, P., Die Beziehungen der Wolframite- und Bleierzlagerstätten Westspaniens zu Graniten und zur Tektonik: *Deut. Geol. Ges. z. Monatsb.*, vol. 80 (1-2), pp. 34-46, April 10, 1928. Abstract in *Annotated Bibliography of Econ. Geology*, no. 210, 1928.

¹³ Dunn, E. J., Tin ore at Glen Wills: *Records Geol. Survey Victoria*, vol. 2, pt. 2, pp. 104-105, 1907.

¹⁴ Reid, A. McIntosh, The mining fields of Morina, Mt. Claude, and Lorinna: *Tasmania Geol. Survey, Bull.* 29, pp. 34-36, 1919.

¹⁵ *Op. cit.*, pp. 300-311.

¹⁶ Dolmage, Victor, Finlay River district, British Columbia: *Canadian Min.*

matites, some of them complex, accompanied the intrusion of the Idaho batholith.¹⁷ The age of this batholith is variously estimated as end of Jurassic, late Cretaceous, and early Eocene.¹⁸ The country rock into which these pegmatites are intruded is pre-Cambrian at several localities. Pegmatites likewise accompany the Mesozoic batholiths of Oregon,¹⁹ Montana,²⁰ Nevada,²¹ and California.²² A number of the minerals found at Crestmore, California, were formed through the action of pre-Cretaceous pegmatite dikes on Paleozoic (?) limestone.²³ The pegmatites of San Diego, California, world famous for their tourmaline crystals and lithium minerals, are of Mesozoic age, probably Jurassic.²⁴

Albite and diabase pegmatites of Triassic age occur in Virginia²⁵ and pyrite-bearing pegmatites occur in the Triassic diabase of the Palisades.²⁶ Pegmatite dikes which are probably related to post-Permian granitic intrusions occur in the Vosges region of France.²⁷ A pegmatitic ore deposit in Austria, of pre-middle Cretaceous age, has been described by Friedrich.²⁸ The rare earth

Jour., vol. 50, no. 8, pp. 164-168; no. 10, pp. 214-217, 229, 1929. Abstract in *Annotated Bibliography of Econ. Geology*, vol. 2, pt. 2, p. 92.

¹⁷ Shannon, E. V., Note on garnet from a pegmatite in Idaho: *Am. Mineral.*, vol. 7, p. 172, 1922. Thomson, F. A., and Ballard, S. M., Geology and gold resources of north-central Idaho: *Idaho Bur. Geology and Mines*, vol. 7, p. 34, 1924.

¹⁸ Anderson, A. L., Genesis of mica pegmatite deposits, Latah County, Idaho: *Econ. Geology*, vol. 28, no. 1, pp. 41-58, 1933.

¹⁹ Goodspeed, G. E., Certain pegmatitic facies of the Wallowa Mountains batholith in northeastern Oregon: *Bull. Geol. Soc. Am.*, vol. 44, pt. 1, p. 160, 1933.

²⁰ Barrell, Joseph, Geology of Marysville mining district, Montana: *U.S. Geol. Survey, Prof. Paper* 57, pp. 16-17, 1907.

²¹ Knopf, A., Geology and ore deposits of the Rochester district, Nevada: *U.S. Geol. Survey, Bull.* 762, p. 52, 1924. Ball, Sydney H., The post-Jurassic igneous rocks of southwestern Nevada: *Jour. Geology*, vol. 16, pp. 43-44, 1908.

²² Turner, H. W., The granitic rocks of the Sierra Nevada: *Jour. Geology*, vol. 7, pp. 141-162, 1899.

²³ Daly, John W., Paragenesis of mineral assemblage at Crestmore: (Abstract) *Pan-American Geologist*, pp. 312-313, May, 1933.

²⁴ Engel, René, Personal communication, dated April 18, 1934.

²⁵ Shannon, E. V., *Proc. U.S. Nat. Mus.*, vol. 66, art. 2, 1924. Abstract in *Mineralog. Abstracts*, vol. 3, p. 204.

²⁶ Kemp, J. F., The role of the igneous rocks in the formation of veins: *Trans. Am. Inst. Min. Engrs.*, vol. 31, p. 182, 1901.

²⁷ Karpinski, R. W., Contribution a l'étude métallogénique des Vosges méridionales, pp. 1-142, Nancy, 1931. Abstract in *Annotated Bibliography of Econ. Geology*, vol. 4, pt. 2, no. 216.

²⁸ Friedrich, O., Eine alte, pegmatitische Erzlagerstätte der Ostalpen: *Neues*

pegmatites occurring in the granite of Ishikawa in the Province of Iwaki in Japan are referred to the Mesozoic, probably Jurassic.²⁹

CENOZOIC PEGMATITES

The area of outcrop of Cenozoic intrusive rocks is relatively small so pegmatites are not abundant. Undoubtedly the number will increase in the geologic future as erosion removes more of the rock overlying the Cenozoic intrusives. A basic pegmatite of probable Tertiary age occurs in the Cooke City district of Montana.³⁰ In the Carlingford district of Ireland, the Carboniferous limestone has been metamorphosed by a series of Tertiary intrusives, ranging from basic to acidic. Pegmatitic satellites of the acidic Tertiary magma reacted with the skarns formed through the earlier metamorphism to produce an unusual suit of minerals.³¹ Another example of Cenozoic pegmatites, in northern Italy immediately south of the southeastern corner of Switzerland, has been described by Cornelius.³² Tertiary pegmatites containing beryl, dumortierite, and uraninite occur in this area.

SUMMARY AND CONCLUSIONS

The greater number of the known pegmatites of the world are pre-Cambrian in age, although Paleozoic and Mesozoic pegmatites are common in areas which have been scenes of intrusive igneous activity during those eras, and Cenozoic pegmatites, although uncommon, are not unknown. There are several reasons for the predominance of pre-Cambrian pegmatites. In the first place the outcrop area of the pre-Cambrian is much greater than that of the younger crystalline rocks. For example, approximately 30 per cent of North America is covered by pre-Cambrian at the surface (or immediately beneath the mantle rock) and of the remaining 70 per cent only a very small proportion is represented

Jahrb., Beil.-Bd. 65, Abt. A (3), pp. 479-503, 1932. Abstract in *Annotated Bibliography of Econ. Geology*, vol. 5, pt. 2, no. 251.

²⁹ Holmes, Arthur, *Op. cit.*, p. 315.

³⁰ Lovering, T. S., Magmatic chalcopryite, Park County, Montana: *Econ. Geology*, vol. 19, pp. 636-640, 1924.

³¹ Osborne, G. D., The metamorphic limestones and associated contaminated igneous rocks of the Carlingford district, Co. Louth: *Geol. Mag.*, vol. 69, no. 815, pp. 209-233, 1932.

³² Cornelius, H. P., Über Auftreten und Mineralführung der Pegmatite in Veltlin und seinen Nachbartälern: *Centr. Mineral. Abt. A.*, pp. 281-287, 1928. Abstract in *Annotated Bibliography of Econ. Geology*, vol. 2, pt. 2, no. 224.

by crystalline rock outcrops. Furthermore, the time represented by the exposed pre-Cambrian is over two-thirds of the known span of geologic time. During this long period a number of revolutions which were accompanied by large-scale igneous intrusion and pegmatite mineralization took place. A possible explanation, beside the selective solution theory of Lane³³ or the differential anatexis theory of Eskola³⁴ and others, of the much greater abundance of lit-par-lit pegmatites in the pre-Cambrian lies in the schistose condition of much of the country rock into which the pre-Cambrian batholiths were intruded. This type of surrounding rock encouraged the movement of magmatic liquids along planes of easier penetration. Similar pegmatization of the country rock took place in New England and portions of the Appalachian area during Paleozoic time where the pre-intrusive rock was very similar to much of that in the pre-Cambrian. As a general rule, younger intrusives have encountered rock of much more homogeneous character (in respect to permeability) so that the magmatic solutions, instead of forming lit-par-lit pegmatites, deposited feldspar, quartz, and other minerals in a contact metamorphic aureole in the adjacent rock.

Pegmatites are most abundant where erosion has stripped off the greater part of the cover above the source batholith. But erosion down to the "mountain roots" is not essential. Both Anderson³⁵ and Thomson and Ballard³⁶ have pointed out the upward increase in abundance of pegmatites in the upper part and overlying shell of the Idaho batholith. Similar observations have been made in parts of the Canadian Shield area where pegmatites are very abundant in the country rock adjacent to batholithic cupolas.

DISTRIBUTION

INTRODUCTION

The following pages contain a compilation of pegmatite occurrences throughout the world. Principal localities are listed for

³³ Lane, A. C., Origin of granites as well as metamorphic crystals by selective solution: *Bull. Geol. Soc. Am.*, vol. 24, p. 704, 1913. Size of batholiths: *Op. cit.*, vol. 42, pp. 813-824, 1931.

³⁴ Eskola, Pennti, On the differential anatexis of rocks: *Comptes Rendus Soc. Geol. de Finlande*, vol. 7, pp. 12-25, 1933.

³⁵ Anderson, Alfred L., Geology and mineral resources of eastern Cassia County, Idaho: *Bull. Idaho Bur. Mines and Geology*, vol. 14, pp. 1-164, 1931.

³⁶ Thomson, F. A., and Ballard, S. M., Geology and gold resources of north-central Idaho: *Bull. Idaho Bur. Mines and Geology*, vol. 7, p. 34, 1924.

each geographic division, and brief mention is made of the more important pegmatite types. The nomenclature used is that which was employed by the writer in a recently published classification of pegmatites.³⁷ The discussion under each geographic division is followed by a selected list of references. In addition the following publications were freely drawn upon:

Aitkins, Irene, *Emeralds: U. S. Bur. Mines, Infor. Circ. 6459*, pp. 1-18, 1931; *Tourmaline, U. S. Bur. Mines, Infor. Circ. 6531*, Nov., 1931. Holmes, Arthur, *Radioactivity and geological time: Age of the earth; Physics of the earth—IV*, pp. 124-459, 1931. *Imperial Institute, London*, Beryllium (Glucinum) and Beryl, pp. 3-20, 1931; Lithium, pp. 1-27, 1932. Jones, W. R., *Tin fields of the world, London, 1925*. La-Croix, Alfred, *Mineralogie de Madagascar, Paris, 1922*. Mohr, H., *Der Nutzglimmer, Berlin, Gebrüder Borntraeger*, pp. 1-275, 1930. Petar, Alice V., *Beryllium and beryl: U. S. Bur. Mines, Infor. Circ. 6190*, Nov., 1929. Spence, H. S., *Mica: Canada Dept. Mines*, no. 701, 1929.

Maps are included (Plates I to VI) for each continent. These give the distribution of complex acidic, intermediate, and basic pegmatites. Simple acidic pegmatites are not shown. Their areas of outcrop would include most of the pre-Cambrian shield of the globe and also numerous localities where younger intrusives are exposed. The symbols used on the maps in some instances refer to single pegmatite bodies, but in most cases they are intended to include a district.

The writer appreciates that the following compilation of pegmatite localities is not a complete one. However, he does believe that most of the important pegmatites (those that have yielded specimens of economic or mineralogical interest) have been included. Beside these a large number of minor occurrences of pegmatite are mentioned. The latter are included in order to give an adequate picture of the very widespread distribution of pegmatite bodies.

The writer is grateful to the College Students Employment Project for the services of Robert Ferris as a bibliographic assistant, and to the Graduate Research Committee of the University of Kansas for a grant defraying the cost of the map cuts.

NORTH AMERICA

UNITED STATES

GENERAL REFERENCES: Hess, Frank L., *The pegmatites of the western states: Ore deposits of the western states, Am. Inst. Min.*

³⁷ Landes, Kenneth K., *Origin and classification of pegmatites: Am. Mineral.*, vol. 18, pp. 33-56 and 95-103, 1933.

Engr., p. 535, 1933. Sterrett, D. B., Mica deposits of the U. S.: *U. S. Geol. Survey, Bull.* 740, 1923. Bastin, E. S., Economic

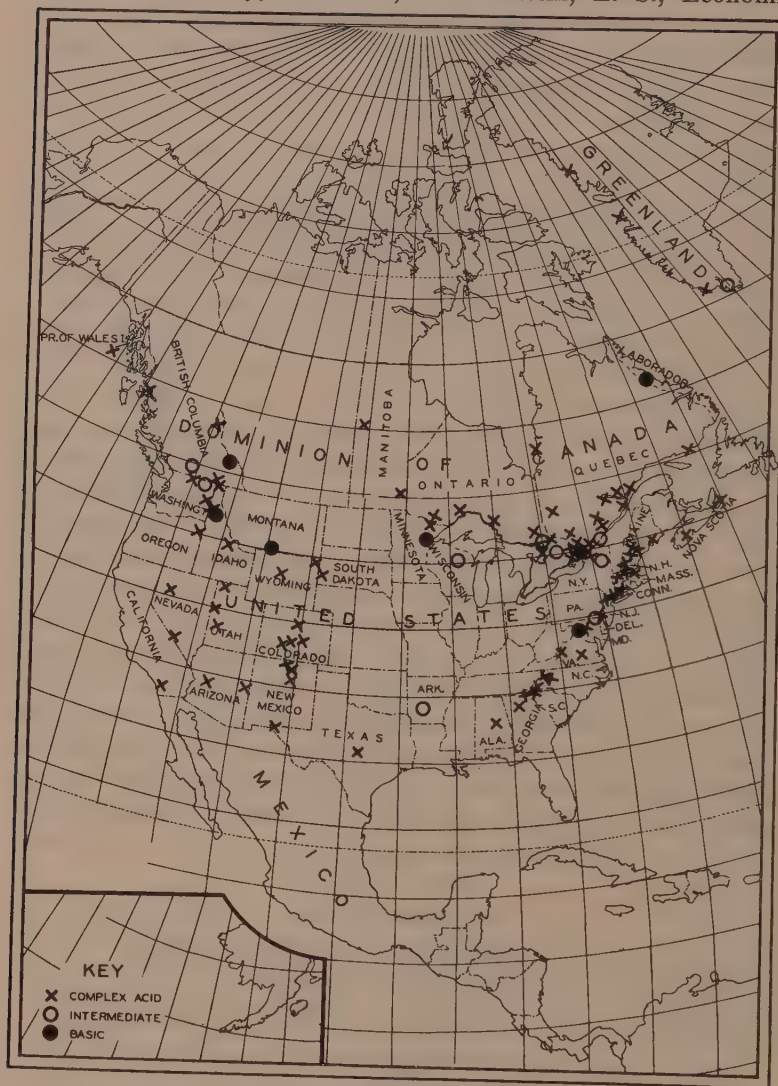


PLATE I. Distribution of complex acidic and intermediate and basic pegmatites in North America.

geology of the feldspar deposits of the United States: *U. S. Geol. Survey, Bull.* 420, 1910.

MAINE. Principal localities: Mainly in Oxford and Androscoggin counties, but some in Sagadahoc, Kennebec, Hancock and other counties. Mount Mica, Mount Apatite, Poland, Rumford, Stoneham, Hebron, Albany, Buckfield, Greenwood, Newry, and Topsham are the more famous place names. Types of pegmatite: Granite, both simple and complex. In the latter beryllium, boron, lithium, phosphate, and fluorine (topaz) phases may be well developed.

REFERENCES: Bastin, Edson S., Geology of the pegmatites and associated rocks of Maine, including feldspar, quartz, mica and gem deposits: *U. S. Geol. Survey, Bull.* **445**, pp. 9-147, 1911. Berman, Harry, and Gonyer, F. A., Pegmatite minerals of Poland, Maine: *Am. Mineral.*, vol. **15**, pp. 375-387, 1930. Fisher, Lloyd W., and Barrell, R., Mount Apatite, Maine: *Rocks and Minerals*, vol. **9**, no. 2, pp. 13-16, Feb., 1934. Fraser, H. J., Paragenesis of the Newry pegmatite, Maine: *Am. Mineral.*, vol. **15**, pp. 349-364, 1930. Gedney, E. K., and Berman, Harry, Huge beryl crystals from Albany, Maine: *Rocks and Minerals*, vol. **4**, pp. 78-80, 1929. Landes, Kenneth K., The paragenesis of the granite pegmatites of central Maine: *Am. Mineral.*, vol. **10**, no. 11, pp. 355-411, Nov., 1925. Palache, Charles, A topaz deposit in Topsham, Maine: *Am. Jour. Sci.*, vol. **27**, pp. 37-48, 1934.

NEW HAMPSHIRE. Principal areas: Grafton and Cheshire counties; also Sullivan, Merrimack, and Hillsboro. Important localities are Grafton, Orange, Rumney, Alexandria, Acworth (and South Acworth), Sullivan, Gilsum, Alstead, Roxbury, Danbury, Baldface Mt., and Milford. Types of pegmatite: Many are granite complex, with beryllium, fluorine, and boron (tourmaline) phases. Milford pegmatite is granodiorite.

REFERENCES: Billings, Marland P., Topaz and phenacite from Baldface Mountain, Chatham, New Hampshire: *Am. Mineral.*, vol. **12**, no. 4, pp. 173-179, 1927. Dale, F. N., The granites of Massachusetts, New Hampshire, and Rhode Island: *U. S. Geol. Survey, Bull.* **354**, 1908. Megathlin, G. R., Spodumene and autunite from Alstead, New Hampshire: *Am. Mineral.*, vol. **13**, no. 12, pp. 578-579, 1928. Flint, George M., Famous mineral localities; Beryl Hill, Grafton, New Hampshire: *Am. Mineral.*, vol. **4**, no. 3, pp. 21-22, 1929. Holden, Edward F., Famous mineral localities; Beryl Mountain, Acworth, New Hampshire: *Am. Mineral.*, vol. **3**, pp. 199-200, 1918. Megathlin, G. R., The pegmatite dikes of the Gilsum area, New Hampshire: *Econ. Geology*, vol. **24**, no. 2, pp. 163-181, 1929.

VERMONT. Localities: Barre, Chester, and Robeson Mt. (Woodbury). Type: Granite simple.

REFERENCE: Dale, T. N., The granites of Vermont: *U. S. Geol. Survey, Bull.* **404**, pp. 1-138, 1909.

MASSACHUSETTS. Principal localities: Chesterfield, Goshen, Lithia, Royalston, Northfield, Uxbridge, Quincy, Winchester,

Rockport (Cape Ann), and western Hampden County. Types of pegmatite: Common granite and alkaline granite (Quincy and Rockport). Some are complex with boron, lithium, beryllium, or rare earth phases. Pegmatites containing diopside intrude limestone in western Massachusetts.

REFERENCES: Browne, Betty V., A visit to the Lithia and Plainfield, Mass., localities: *Rocks and Minerals*, vol. 8, pp. 115-116, 1933. Emerson, B. K., Northfieldite, pegmatite, and pegmatite schist: *Am. Jour. Sci.*, (4) vol. 40, pp. 212-217, 1915. Eskola, Pentti, On contact phenomena between gneiss and limestone in western Massachusetts: *Jour. Geology*, vol. 30, pp. 265-294, 1922. Jaggard, T. A., Jr., An occurrence of acid pegmatite in diabase: *Am. Geologist*, vol. 21, pp. 203-213, 1898. Warren, C. H., and McKinstry, Hugh E., The granites and pegmatites of Cape Ann, Massachusetts: *Proc. Am. Acad. Arts and Science*, vol. 59, no. 14, pp. 315-357, 1924. Warren, C. H., and Palache, Charles: The pegmatites of the riebeckite-aegirite granite of Quincy, Massachusetts, U.S.A.; their structure, minerals, and origin: *Proc. Am. Acad. Arts and Science*, vol. 47, pp. 125-168, 1911.

RHODE ISLAND. Principal localities: Southwestern Rhode Island in the vicinity of Westerly, west coast of Narragansett Bay, and Diamond Hill. Types of pegmatite: Granite, mainly simple, and alkaline granite (Diamond Hill).

REFERENCES: Lahee, F. H., Relations of the degree of metamorphism to geologic structure and to acid igneous intrusion in the Narragansett Basin, Rhode Island: *Am. Jour. Sci.* (4), vol. 33, pp. 249-262; 354-372; 447-469, 1912.

CONNECTICUT. Principal localities: Portland, Middletown, South Glastonbury, Haddam Neck, Trumbull, Branchville, New Milford, and Chatham. Types of pegmatite: Granite, the larger ones complex. A lithium phase is prominent at Chatham, a beryllium phase at Haddam Neck, a phosphate phase at Branchville, a fluorine phase at Trumbull, and both lithium and phosphate phases at Portland.

REFERENCES: Bowman, H. L., On an occurrence of minerals at Haddam Neck, Conn.: *Min. Mag.*, vol. 13, pp. 97-121, 1902. Brush, G. J., and Dana, E. S., On the mineral locality at Branchville: *Am. Jour. Sci.* (3), vol. 39, pp. 201-216, 1890. Foye, W. G., Mineral localities in the vicinity of Middletown, Connecticut: *Am. Mineral.*, vol. 7, pp. 4-12, 1922. Schairer, J. F., The minerals of Connecticut: *Conn. Geol. and Nat. Hist. Survey, Bull.* 51, 1931. Shannon, E. V., Strickland's quarry, Portland, Connecticut: *Am. Mineral.*, vol. 5, no. 3, pp. 51-54, 1920. Shannon, E. V., The old lithia mine in Chatham, Connecticut: *Am. Mineral.*, vol. 5, no. 4, pp. 82-84, 1920.

NEW YORK. Principal localities: Pierrepont, De Kalb and Gouverneur in St. Lawrence County; Saratoga and Fulton counties;

Chester, Bedford, and New York City; and many localities in the Adirondacks. Types of pegmatite: Granite, and in the Adirondacks granodiorite (or quartz-diorite) and diorite. The Fordham gneiss is thoroughly impregnated with pegmatite. The Bedford pegmatite is complex with a rare earth phase, a boron phase is present in several of the St. Lawrence County deposits, and many of the pegmatites in the Adirondacks have an iron ore (magnetite) phase.

REFERENCES: Agar, Wm. M., The pegmatites of Bedford, New York: *Sixteenth International Geol. Congress, Guidebook 9*, pp. 123-128, 1933. Alling, Harold L., Genesis of the Adirondack magnetites: *Econ. Geology*, vol. 20, pp. 335-363, 1925. Colony, R. J., Structural geology between New York and Schunemunk Mt.: *Sixteenth International Geol. Congress, Guidebook 9*, pp. 19-44, 1933. Miller, Wm. J., Pegmatite, silicite, and aplite of northern New York: *Jour. Geology*, vol. 27, pp. 28-55, 1919. Newland, D. H., Structures in Adirondack magnetites: *Bull. Geol. Soc. America*, vol. 42, p. 238, 1931. Shaub, B. M., A unique feldspar deposit near De Kalb Junction, New York: *Econ. Geology*, vol. 24, no. 1, pp. 68-69, 1929.

NEW JERSEY. Principal localities: Abundant in the pre-Cambrian crystalline rocks composing the highlands of northern New Jersey. A minor occurrence is in the Triassic diabase of the Palisades. Types of pegmatite: Granite, in a number of localities with a magnetite phase.

REFERENCES: Bayley, W. S., Iron mines and iron mining in New Jersey: *New Jersey Survey, Final Report*, vol. 7, 1910. Kemp, J. F., The role of the igneous rocks in the formation of veins: *Trans. Am. Inst. Min. Eng.*, vol. 31, pp. 182-183, 1901. Palache, Charles, Paragenetic classification of the minerals of Franklin, N.J.: *Am. Mineral.*, vol. 14, no. 1, pp. 1-18, 1929. Ries, H., and Bowen, W. C., Origin of the zinc ores of Sussex County, New Jersey: *Econ. Geology*, vol. 17, pp. 517-571, 1922. Smith, Lawrence, L., Magnetite ores of northern New Jersey: *Econ. Geology*, vol. 28, pp. 658-677, 1933. Spencer, A., Description of Franklin Furnace quadrangle, New Jersey: *U. S. Geol. Survey, Folio 161*, pp. 1-27, 1908.

PENNSYLVANIA. Principal localities: Southeastern Pennsylvania, especially Chester and Delaware counties. Types of pegmatite: Simple granite, granite complex with beryllium and iron ore (magnetite) phases, and syenite pegmatite ("soda pegmatites" of Bastin) adjacent to the Maryland line.

REFERENCES: Miller, B. L., The geology of the graphite deposits of Pennsylvania: *Econ. Geology*, vol. 7, pp. 762-777, 1912. Stone, Ralph W., and Hughes, H. Herbert, Feldspar in Pennsylvania: *Pa. Geol. Survey, 4th ser., Bull. M13*, pp. 7-63, 1931.

DELAWARE. Simple pegmatites occur at the northern end of the state adjacent to Pennsylvania.

REFERENCE: Bascom, F., and Stose, G. W., Coatesville and West Chester quadrangles, Pennsylvania-Delaware: *U. S. Geol. Survey, Geologic Folio* **223**, pp. 1-15, 1932.

MARYLAND. Principal localities: Montgomery, Howard and Baltimore counties, and Cecil County in the northeastern corner. Types of pegmatite: Granite, except for syenite pegmatites in Cecil County adjacent to Pennsylvania. Complex pegmatite in Montgomery County. Diopside in Howard County pegmatite due to intrusion into dolomite.

REFERENCES: Shannon, E. V., Some minerals from the Kensington mica mine, Montgomery County, Maryland: *Am. Mineral.*, vol. **11**, no. 2, pp. 35-37, 1926. Watson, E. H., A diopside-bearing pegmatite in dolomite: *Econ. Geology*, vol. **24**, no. 6, pp. 611-625, 1929. Williams, G. H., Origin of the Maryland pegmatites: *U. S. Geol. Survey, 15th Ann. Rept.*, pp. 675-685, 1895. Williams, G. H., The gabbros, etc., in the neighborhood of Baltimore, Maryland: *U. S. Geol. Survey, Bull.* **28**, 1886.

VIRGINIA. Principal localities: East-central Virginia, especially Amelia, Goochland, and Hanover counties; west-central Virginia, especially Rockbridge, Amherst and Henry counties, and Loudoun County in northern Virginia. Types of pegmatite: Granite, many of them complex with titanium, zirconium, and rare earth phases prominent. Kyanite occurs in pegmatite in southwestern Virginia. Diabase pegmatites of Triassic age occur in Loudoun County.

REFERENCES: Jonas, A. I., and Watkins, J. H., Kyanite in Virginia: *Virginia Geol. Survey, Bull.* **38**, pp. 1-52, 1932. Lonsdale, John T., Geology of the gold-pyrite belt of the northeastern piedmont, Virginia: *Virginia Geol. Survey, Bull.* **30**, pp. 1-110, 1927. Pegau, A. A., Pegmatite deposits of Virginia: *Virginia Geol. Survey, Bull.* **33**, pp. 1-123, 1932. Ross, C. S., Titanium deposits of Roseland district: *Sixteenth International Geol. Congress, Guidebook* **11**, pp. 29-36, 1933. Shannon, E. V., The mineralogy and petrology of intrusive Triassic diabase at Goose Creek, Loudoun County, Virginia: *Proc. U. S. Nat. Mus.*, vol. **66**, art. 2, 1924. Watson, T. L., Zircon-bearing pegmatites in Virginia: *Trans. Am. Inst. Min. Eng.*, vol. **55**, pp. 936-942, 1917. Watson, T. L., and Taber, S., Geology of the titanium and apatite deposits of Virginia: *Virginia Geol. Survey, Bull.* **3A**, pp. 1-308, 1913.

NORTH CAROLINA. Principal localities: Pre-Cambrian crystalline rock area toward the western end of the state, especially in Alexander, Cleveland, Burke, Mitchell, Yancey, Avery, Haywood, Macon, and Jackson counties. Types of pegmatite: Granite simple and complex. Latter exhibit the following phases: rare earth (especially at Spruce Pine), magnetite (Cranberry), tin, and beryllium (producing common beryl, aquamarine, and emerald)

Kyanite and hiddenite are unusual pegmatite minerals found in North Carolina.

REFERENCES: Bayley, W. S., Magnetic iron ores of eastern Tennessee and western North Carolina: *North Carolina Geol. and Econ. Survey, Bull.* **32**, pp. 1-252, 1923. Hall, George M., Zoisite and other minerals included in mica from Spruce Pine, North Carolina: *Am. Mineral.*, vol. **19**, no. 2, pp. 76-80, 1934. Keith, Arthur, Gaffney-Kings Mountain Folio, South and North Carolina: *U. S. Geol. Survey, Geologic Folio* **222**, 1931. Palache, Charles, Davidson, S. C., and Goranson, E. A., The hiddenite deposit in Alexander County, North Carolina: *Am. Mineral.*, vol. **15**, pp. 280-302, 1930. Schaller, W. T., A large monazite crystal from North Carolina: *Am. Mineral.*, vol. **18**, no. 10, pp. 435-439, 1933. Stuckey, J. L., Cyanite deposits of North Carolina: *Econ. Geology*, vol. **27**, no. 7, pp. 661-674, 1932.

SOUTH CAROLINA. Principal localities: The extreme western part of the state, especially Anderson and Greenville counties. Types of pegmatite: Granite, with a beryllium phase in Anderson County.

REFERENCE: Keith, Arthur, Gaffney-Kings Mt. Folio, South and North Carolina: *U. S. Geol. Survey, Geol. Folio* **222**, 1931.

GEORGIA. Principal localities: Pegmatites are widely scattered through at least 20 counties in the crystalline rock belt of Georgia which covers most of the northern half of the state. Types of pegmatite: Granite, mostly simple. Beryl occurs in pegmatite in Rabun County.

REFERENCES: Galpin, S. L., A preliminary report on the feldspar and mica deposits of Georgia: *Georgia Geol. Survey, Bull.* **30**, 1915. Watson, T. L., On the occurrence of aplite, pegmatite and tourmaline bunches in the Stone Mountain granite of Georgia: *Jour. Geology*, vol. **10**, pp. 186-193, 1902.

ALABAMA. Principal localities: In east-central Alabama, mainly Randolph, Clay, Tallapoosa, and Coosa counties. Types of pegmatite: Mostly granite simple. Beryllium phase in Randolph and Coosa counties.

REFERENCES: Brown, J. S., Graphite deposits of Ashland, Alabama: *Econ. Geology*, vol. **20**, p. 224, 1925. Van Horn, F. R., Occurrence of a large iron-tourmaline in Alabama pegmatites: *Am. Mineral.*, vol. **10**, no. 10, pp. 348-350, 1925.

TEXAS. Principal localities: Culberson and El Paso counties in western Texas, and Baringer Hill and adjacent pegmatites in Llano and Mason counties in the Central Mineral Region. Types of pegmatite: Granite, with a rare earth phase in the Baringer Hill neighborhood and a tin phase in the Franklin Mountains in El Paso County.

REFERENCES: Hess, F. L., Minerals of the rare-earth metals at Baringer Hill, Llano County, Texas: *U. S. Geol. Survey, Bull.* **340**, pp. 286-294, 1908. Landes, K. K., The

Baringer Hill, Texas, pegmatite: *Am. Mineral.*, vol. 17, no. 8, pp. 381-390, 1932.
Paige, S., Description of Llano and Burnet quadrangles: *U. S. Geol. Survey, Folio* 183, 1912.

ARKANSAS. Locality: Magnet Cove. Type of pegmatite: Nephelite-syenite with rare alkaline mineral phase.

REFERENCES: Landes, K. K., A paragenetic classification of the Magnet Cove minerals: *Am. Mineral.*, vol. 16, no. 8, pp. 313-326, 1931. Williams, J. F., Igneous rocks of Arkansas: *Arkansas Geol. Survey, Ann. Rept.*, vol. 11, 1890.

OKLAHOMA. Locality: Pre-Cambrian crystalline rock exposure in Wichita Mountains, southwestern Oklahoma. Types of pegmatite: Alkaline granite (Greer County) and zircon pegmatite near Indianahoma.

REFERENCE: Rogers, A. F., Aegirite and riebeckite rocks from Oklahoma: *Jour. Geology*, vol. 12, pp. 283-287, 1907.

MISSOURI. Locality: Camden County, western Missouri. Type of pegmatite: Granite, simple.

REFERENCE: Gould, Charles N., Crystalline rocks of the plains: *Bull. Geol. Soc. America*, vol. 34, pp. 541-560, Sept., 1923.

MICHIGAN. Pegmatite localities: Pre-Cambrian portion of the upper peninsula. Type of pegmatite: Granite, simple.

REFERENCES: Lamey, C. A., The intrusive relations of the Republic granite: *Jour. Geology*, vol. 41, no. 5, p. 490, 1933. Van Hise, C. R., Treatise on metamorphism: *U. S. Geol. Survey, Mon.* 47, p. 725, 1904.

WISCONSIN. Pegmatite localities: Pre-Cambrian area of north central Wisconsin. Types of pegmatite: Granite and nephelite-syenite.

REFERENCE: Weidman, S., The geology of north-central Wisconsin: *Wisconsin Geol. and Nat. Hist. Survey, Bull.* 16, pp. 1-697, 1907.

MINNESOTA. Pegmatite localities: Pre-Cambrian area, especially the northern part of the state. Types of pegmatite: Granite, some with a magnetite phase, and gabbro in the vicinity of the Duluth gabbro.

REFERENCES: Grout, F. F., Magnetite pegmatites of northern Minnesota: *Econ. Geology*, vol. 18, pp. 253-269, 1923. Grout, F. F., The pegmatites of the Duluth gabbro: *Econ. Geology*, vol. 13, pp. 185-197, 1918. Grout, F. F., Contact metamorphism of the slates of Minnesota by granite and by gabbro magmas: *Bull. Geol. Soc. America.*, vol. 44, no. 5, pp. 989-1040, 1933.

SOUTH DAKOTA. Principal localities: Confined to the pre-Cambrian area of the Black Hills, especially the vicinities of Key-

stone and Custer. Types of pegmatite: Granite simple and complex, with strong lithium phase and less marked beryllium and tin ore phases in several.

REFERENCES: Connolly, J. P., and O'Harra, C. C., The mineral wealth of the Black Hills: *South Dakota School of Mines, Bull.* **16**, pp. 1-418, 1929. Darton, N. H., and Paige, Sidney, Central Black Hills folio, South Dakota: *U. S. Geol. Survey, Folio* **219**. Hess, Frank L., Tin, tungsten, and tantalum deposits of South Dakota: *U. S. Geol. Survey, Bull.* **380**, pp. 131-161, 1909. Hess, Frank L., The natural history of the pegmatites: *Eng. and Min. Jour.*, vol. **120**, no. 8, pp. 289-298, Aug. 22, 1925. Landes, Kenneth K., Sequence of mineralization in the Kcystone, South Dakota, pegmatites: *Am. Mineral.*, vol. **13**, pp. 519-530; 537-558, Oct., Nov., 1928. Schwartz, G. M., Geology of the Etta spodumene mine, Black Hills, South Dakota: *Econ. Geology*, vol. **20**, pp. 646-659, 1925. Schwartz, G. M., The Tin Mt. spodumene mine, Black Hills, South Dakota: *Econ. Geology*, vol. **25**, no. 3, pp. 275-284, 1930. Ziegler, V., The minerals of the Black Hills: *South Dakota School of Mines, Bull.* **10**, 1914.

MONTANA. Principal localities: Associated with the intrusive rocks in the western part of the state. Types of pegmatite: Granite (simple) and basic.

REFERENCES: Barrell, Joseph., Geology of Marysville mining district, Montana: *U. S. Geol. Survey, Prof. Paper* **57**, pp. 1-178, 1907. Emmons, W. H., Geology of the Haystack stock, Cowles, Park County, Montana: *Jour. Geology*, vol. **16**, pp. 193-229, 1908. Lovering, T. S., Magmatic chalcopryrite, Park County, Montana: *Econ. Geology*, vol. **19**, pp. 636-640, 1924. Weed, W. H., and Barrell, J., Geology and ore deposits of the Elkhorn mining district, Jefferson County, Montana: *U. S. Geol. Survey, 22nd Ann. Rept.*, pt. **2**, pp. 399-550, 1901. Winchell, A. N., A theory for the origin of graphite as exemplified in the graphite deposit near Dillon, Montana: *Econ. Geology*, vol. **6**, pp. 218-230, 1911.

WYOMING. Principal localities: Widely scattered in the pre-Cambrian areas of Laramie, Albany, and Carbon counties in the southeastern part of the state, in northern Fremont County in west-central Wyoming, and along the eastern edge of Crook County in the northeast corner where the Black Hills extend into Wyoming. Types of pegmatite: Granite, mainly simple. Fremont County pegmatites are complex, containing lithium minerals and beryl, and Crook County pegmatites contain cassiterite.

REFERENCES: Ball, Sidney H., Mica in the Hartville Uplift, Wyoming: *U. S. Geol. Survey, Bull.* **315**, pp. 423-428, 1906. Swartzlow, Carl R., *Personal communication*, Jan. 3, 1934.

COLORADO. Principal localities: In practically every county in the Front Range extending from the Wyoming line south to Fremont County in south central Colorado and in pre-Cambrian areas to the westward. Types of pegmatite: Mainly granite and

quartz monzonite. A fluorine phase is well developed in the Pikes Peak-St. Peter's Dome region. Ore mineral phases occur in Boulder County and in the Georgetown district (magnetite). A newly-described pegmatite near Ohio City in the Gunnison Valley exhibits a strong lithium phase. A beryllium phase is important at Mount Antero and elsewhere in the upper Arkansas River valley.

REFERENCES: Eckel, Edwin B., A new lepidolite deposit in Colorado: *Jour. Am. Ceramic Soc.*, vol. 16, no. 5, pp. 239-245, May, 1933. Lindgren, W., Some gold and tungsten deposits of Boulder County, Colorado: *Econ. Geology*, vol. 2, pp. 453-463, 1907. Palache, C., and Over, Edwin, Jr., Pegmatites of the Pikes Peak region, Colorado: Abstract, *Am. Mineral.*, vol. 18, p. 115, 1933. Spurr, J. E., and Garrey, G. H., Preliminary report on the ore deposits in the Georgetown, Colorado, mining district: *U. S. Geol. Survey, Bull.* 260, 1905; *U. S. Geol. Survey, Prof. Paper* 63, p. 60 et seq.

NEW MEXICO. Principal localities: In north-central New Mexico on both sides of the county line separating Rio Arriba and Taos counties and southeastward into Mora and San Miguel counties. Types of pegmatite: Granite simple, and complex with a rare earth phase near Petaca, Rio Arriba County, a lithium phase in the vicinity of Embudo in Taos County, and a molybdenite phase near Porvenir in San Miguel County.

REFERENCES: Hess, F. L., and Wells, R. C., Samarskite from Petaca, New Mexico: *Am. Jour. Sci.*, vol. 19, no. 109, pp. 17-26, Jan., 1930. Horton, F. W., Molybdenite, its ores and their concentration: *U. S. Bur. Mines, Bull.* 111, p. 78, 1916. Roos, Alford, Mining lepidolite in New Mexico: *Eng. and Min. Jour.*, vol. 121, no. 26, pp. 1037-1042, 1926. Schaller, W. T., and Henderson, E. P., Purple muscovite from New Mexico: *Am. Mineral.*, vol. 11, pp. 5-15, 1926.

ARIZONA. Principal localities: Central Arizona, and the Archean rocks of the Inner Gorge of Colorado River. Types of pegmatite: Granite, mostly simple. Complex with phosphate phase near Hillside in west-central Arizona. Tungsten ore (wolframite) phase at Cave Springs in east-central Arizona.

REFERENCES: Bastin, E. S., Primary native silver ores near Wickenburg, Arizona: *U. S. Geol. Survey, Bull.* 735, pp. 131-155, 1922. Campbell, I., and Maxson, J. H., Some observations on the Archean metamorphics of the Grand Canyon: *Proc. Nat. Acad. Sci.*, vol. 19, no. 9, pp. 806-809, Sept., 1933. Hurlburt, C. S., Jr., and Gonyer, F. A., New group of phosphates: *Geol. Soc. America, Proc.* for 1933, p. 440, 1934. Lausen, Carl, Tourmaline-bearing cinnabar veins of the Mazatzal Mountains, Arizona: *Econ. Geology*, vol. 21, pp. 782-791, Dec., 1926.

UTAH. Principal localities: Park Valley district in northwestern Utah; Deep Creek Mountains south of Gold Hill in west-central Utah; and Beaver and San Francisco ranges in southwestern Utah.

Types of pegmatite: Granite and quartz monzonite. Complex with ore mineral phase at Park Valley, Spring Creek (Deep Creek Mountains), and Beaver Lake. Beryl also present in Deep Creek Mountains.

REFERENCE: Butler, B. S., Ore deposits of Utah: *U. S. Geol. Survey, Prof. Paper* 111, p. 159, 1920.

IDAHO. Principal localities: In and surrounding the great batholith of north-central Idaho, especially in Latah County, and in Cassia County in southern Idaho. Types of pegmatite: Granite, mainly simple. Some beryl is found in the Latah County deposits and molybdenite occurs in pegmatites in Boundary and Lemhi counties. A hornblende pegmatite has been found in western Clearwater County.

REFERENCES: Anderson, A. L., Genesis of mica pegmatite deposits, Latah County, Idaho: *Econ. Geology*, vol. 28, no. 1, pp. 41-58, 1933. Anderson, A. L., Geology and mineral resources of eastern Cassia County, Idaho: *Idaho Bur. Mines and Geology, Bull.* 14, pp. 1-164, 1931. Anderson, A. L., An occurrence of giant hornblende: *Jour. Geology*, vol. 41, no. 1, pp. 89-98, 1933. Livingston, D. C., Tungsten, cinnabar, manganese, molybdenum, and tin deposits of Idaho: *Univ. of Idaho School of Mines*, vol. 14, Bull. 2, pp. 40-41, 1919. Shannon, E. V., Note on garnet from a pegmatite in Idaho: *Am. Mineral.*, vol. 7, pp. 171-173, 1922. Thomson, F. A., and Ballard, S. M., Geology and gold resources of north-central Idaho: *Idaho Bur. Mines and Geology*, vol. 7, p. 34, 1924.

NEVADA. Principal localities: A few widely scattered pegmatites have been reported from the southeastern (northeastern Clark County) and southwestern (especially Bullfrog Hills) parts of the state and from the Rochester mining district in northwest central Nevada. Types of pegmatite: Granite, with a gold phase in the Rochester district and a molybdenite phase in southwestern Nevada.

REFERENCES: Ball, Sydney H., The post-Jurassic igneous rocks of southwestern Nevada: *Jour. Geology*, vol. 16, pp. 36-45, 1908. Knopf, A., Geology and ore deposits of the Rochester district, Nevada: *U. S. Geol. Survey, Bull.* 762, pp. 1-78, 1924.

CALIFORNIA. Principal localities: Pegmatites have been reported from about 14 counties scattered over northern, east-central, and southern California. The most important district is in Riverside and San Diego counties in southern California. Types of pegmatite: Granodiorite simple in Sierra Nevada ranges in east-central and northern California. Granite complex in San Diego and Riverside counties with a very prominent lithium phase.

Other phases present are boron (tourmaline), beryllium, molybdenum, and rare earth (monazite).

REFERENCES: Calkins, F. C., Molybdenite near Ramona, San Diego County, California: *U. S. Geol. Survey, Bull.* **640-D**, pp. 73-76, 1916. Dykes, Leland H., Occurrence of monazite in a granodiorite pegmatite in Riverside County, California: *Bull. Geol. Soc. America*, vol. **44**, pt. 1, p. 161, 1933. Eakle, A. S., Minerals associated with the crystalline limestone at Crestmore, Riverside County, California: *Univ. California, Geol. Bull.* **10**, pp. 327-360, 1917. Hess, F. L., Some molybdenite deposits of Maine, Utah, and California: *U. S. Geol. Survey, Bull.* **340**, pp. 231-240, 1908. Hudson, F. S., Geology of the Cuyamaca region of California: *Univ. of Calif., Pub. in Geology*, vol. **13**, no. 6, pp. 175-252, June, 1922. Rogers, A. F., Minerals from the pegmatite veins of Rincon, San Diego County, California: *School of Mines, Quart.*, vol. **31**, pp. 208-218, 1910. Schaller, W. T., The genesis of lithium pegmatites: *Am. Jour. Sci.*, vol. **10**, pp. 269-279, Sept., 1925. Waring, G. A., The pegmatite veins of Pala, San Diego County, California: *Am. Geologist*, vol. **35**, pp. 356-369, 1905.

OREGON. Locality: Wallowa Mountains in the northeastern part of the state. Type of pegmatite: Granodiorite.

REFERENCE: Goodspeed, G. E., Certain pegmatite facies of the Wallowa Mountains batholith in northeastern Oregon: *Bull. Geol. Soc. America*, vol. **44**, pt. 1, p. 160, 1933.

WASHINGTON. Principal localities: Silver Hill, near Spokane, Ferry and Okanogan counties in the northeastern part of the state, Chelan County in north-central Washington, and Bald Butte Ridge in southeastern Washington. Types of pegmatite: Mainly granite simple. The Silver Hill pegmatite is complex with a tin phase and molybdenite-bearing pegmatites occur in central and northern Okanogan County. The pegmatites in northern Ferry County are complex syenite with a copper sulphide phase.

REFERENCES: Anderson, A. L., Genesis of Silver Hill tin deposits: *Jour. Geology*, vol. **36**, pp. 646-664, Oct.-Nov., 1928. Hoffman, Malvin, G., The geology of Bald Butte Ridge, Washington: *Jour. Geology*, vol. **40**, no. 7, pp. 634-650, 1932. Horton, F. W., Molybdenite; its ores and their concentration: *U. S. Bur. Mines, Bull.* **111**, p. 78, 1916. Jones, E. L., Jr., Reconnaissance of the Conconully and Ruby mining districts, Washington: *U. S. Geol. Survey, Bull.* **640**, pp. 11-36, 1916. McLaughlin, D. H., Copper sulphides in syenite and pegmatite dikes: *Econ. Geology*, vol. **14**, no. 5, pp. 403-410, 1919. Richarz, Stephen, Peculiar gneisses and ore formations in the eastern Cascades, Washington: *Jour. Geology*, vol. **41**, no. 7, pp. 757-768, 1933. Waters, A. C., A petrologic and structural study of the Swakane gneiss, Entiat Mountains, Washington: *Jour. Geology*, vol. **40**, no. 7, pp. 604-633, 1932.

ALASKA. Principal localities: In Coast Range intrusives in southeastern Alaska and widely scattered occurrences in the in-

terior. Types: Granite simple mainly Complex with sulphide phase at Shakan, southeastern Alaska.

REFERENCES: Brooks, A. H., Reconnaissance in the Tanana and White River basins, Alaska, in 1898: *U. S. Geol. Survey*, 20th Ann. Rept., pt. 7, pp. 425-494, 1898-99. Brooks, A. H., Preliminary report on the Ketchikan district, Alaska: *U. S. Geol. Survey, Prof. Paper* 1, 1902. Buddington, A. F., Molybdenite deposit at Shakan, Alaska: *Econ. Geology*, vol. 25, no. 2, pp. 197-200, 1930. Buddington, A. F., Coincident variations of types of mineralization of Coast Range intrusives: *Econ. Geology*, vol. 22, pp. 158-179, 1927. Spurr, J. E., Geology of the Yukon District, Alaska: *U. S. Geol. Survey*, 18th Ann. Rept., pt. 3, pp. 1-392, 1896-97.

CANADA

GENERAL REFERENCES: Eardley-Wilmot, V. L., Molybdenum: *Canada Dept. Mines, Mines Branch*, no. 592, pp. 1-292, 1925. Ellsworth, H. V., Rare element minerals of Canada: *Canada Geol. Survey, Econ. Geology Ser.* no. 11, pp. 1-272, 1932. Gwillim, J. C., Molybdenite in Nova Scotia, Quebec, Ontario, and British Columbia: *Munition Resources Commission, Canada, Final Rept.*, pp. 104-133, 1920. Spence, H. S., Notes on beryllium and beryl: *Canada Dept. Mines, Mines Branch, Memo. Ser.* no. 40, pp. 1-16, April, 1930. Spence, Hugh S., Pegmatite minerals of Ontario and Quebec: *Am. Mineral.*, vol. 15, no. 9, pp. 430-450; 474-495, 1930. Spence, Hugh S., Feldspar: *Canada Dept. Mines, Mines Branch*, no. 731, pp. 1-145, 1932. Walker, T. L., Molybdenite ores of Canada: *Canada Dept. Mines, Mines Branch*, no. 93, pp. 1-64, 1911. Young, G. A., Geology and economic minerals of Canada: *Canada Geol. Survey*, no. 2065, 1926.

NEWFOUNDLAND, LABRADOR, AND BAFFIN ISLAND. Principal localities: Widely scattered over pre-Cambrian shield; also in ultrabasic rocks of Labrador coast. Types: Granite simple; pure labradorite pegmatites in Labrador.

NOVA SCOTIA. Principal localities: Lunenburg (especially New Ross), Halifax, and Cape Breton counties. Type: Granite. Complex pegmatites with lithium and ore mineral phases occur in Lunenburg County and a molybdenite phase is found near Cape Breton.

REFERENCES: Cook, C. W., Molybdenite deposit near New Ross, Nova Scotia: *Econ. Geology*, vol. 20, pp. 185-188, 1925. Davison, E. H., Tin lodes in Nova Scotia: *Mining Mag.*, vol. 42, no. 1, pp. 20-23, 1930. Faribault, R., Lunenburg County, Nova Scotia: *Geol. Survey Canada, Summary Rept. for* 1907, pp. 78-83, 1908.

Walker, T. L., and Parsons, A. L., Pegmatite minerals from New Ross, Nova Scotia: *Univ. Toronto Studies, Geol. Ser.* no. 17, pp. 46-50, 1924.

QUEBEC. Principal localities: Widely scattered over the great pre-Cambrian shield; and in the Paleozoic intrusives of Mount Royal, Montreal. Pegmatites are especially abundant in the Abitibi region of southwestern Quebec, in a 100-mile wide strip north of Ottawa River between Calumet Island and Montreal, and north of St. Lawrence River and Gulf of St. Lawrence between Quebec and the east end of the Saguenay district. Types of pegmatite: Mainly granite simple and complex. Latter exhibit an important molybdenite phase at Kewagama Lake and elsewhere in Abitibi district, northwest of Ottawa in Hull-Quyon area, along south shore of Lake St. John, and in the Saguenay district near the mouth of Manikuan River and at Romaine. A rare earth phase occurs in pegmatites near Wakefield (northwest of Hull), Buckingham, in Berthier County north of Montreal, north of Murray Bay (northeast of Quebec), and at several localities in Chicoutimi County east of Lake St. John. Beryllium phases are found in Abitibi district and 100 miles north of Montreal (chrysoberyl). Graphite occurs in pegmatite at Louisa, north of Lachute, and lithium minerals at Wakefield and on Walrus Island, Paint Hills group, James Bay. The pegmatites at Mount Royal are nephelite syenite. Basic pegmatites exhibiting a phlogopite-apatite phase occur north of Ottawa.

REFERENCES: Bain, G. W., Graphite deposits of Louisa, Quebec: *Econ. Geology*, vol. 24, pp. 733-752, Nov. 1929. Camsell, C., Molybdenite deposits of the Moss Mine, Quyon, Quebec: *Canada Geol. Survey, Summary Rept.*, pp. 207-208, 1916. Ellsworth, H. V., Thucholite and uraninite from the Wallingford Mine near Buckingham, Quebec: *Am. Mineral.*, vol. 13, no. 8, pp. 442-448, 1928. Evans, Nevil N., Chrysoberyl from Canada: *Am. Jour. Sci.*, vol. 19, pp. 316-318, 1905. Finley, F. L., The nephelite-syenites and pegmatites of Mount Royal, Montreal, Quebec: *Canadian Jour. Research*, vol. 2, pp. 231-248, 1930. Hawley, J. E., Molybdenite deposits of La Corne township, Abitibi County: *Quebec Bur. Mines, Ann. Rept. for 1930*, pp. 97-122, 1931 (Part C). Thomson, E., A pegmatite origin for molybdenite ores: *Econ. Geology*, vol. 13, pp. 302-313, 1918.

ONTARIO. Principal localities: Widespread over province, but exceedingly abundant in broad belt extending eastward from Sudbury and Georgian Bay to the provincial boundary. Types of pegmatite: Alaskite simple, granite simple and complex, syenite and nephelite syenite simple and complex, and basic complex. Phases present in complex granite pegmatites: Molybdenite in Frontenac,

Renfrew, and Haliburton counties, and Lake Superior and Kenora districts; beryl in Renfrew County and Nipissing and Rainy River districts; rare earth (especially radioactive minerals) in Carleton, Lanark, Renfrew, Hastings and Haliburton counties, and Nipissing, Parry Sound and Sudbury districts; calcite in Hastings and Haliburton counties; lithium in Lanark County; and iron ore in Rainy River district. Syenite (and nephelite syenite) pegmatites occur in Frontenac, Renfrew, and Hastings counties and along French River in the Parry Sound district. These exhibit a corundum phase in Renfrew and Hastings counties. Basic pegmatites have been found near Wilberforce in Haliburton County and in the phlogopite-apatite district of southeastern Ontario.

REFERENCES: Adams, Frank D., and Barlow, Alfred E., Geology of the Haliburton and Bancroft areas, Province of Ontario: *Canada Geol. Survey, Memoir* 6, pp. 139–147, 1910. Barlow, Alfred E., Corundum, its occurrence, distribution, exploitation and uses: *Canada Geol. Survey, Dept. of Mines, Memoir* 57, pp. 1–354, 1915. Ellsworth, H. V., Radium-bearing pegmatites of Ontario: *Geol. Survey Canada, Summary Rept.*, Pt. D, 1921. Ellsworth, H. V., Recent discoveries of radioactive minerals in Ontario: *Canada Geol. Survey, Summary Report*, Pt. CI, 1923. Miller, Willet G., Uranium minerals in Haliburton district, Ontario: *Canadian Min. Jour.*, p. 44, Jan. 11, 1924. Parsons, A. L., Molybdenite deposits of Ontario: *Ontario Bur. Mines, Ann. Rept.* 26, pp. 275–313, 1917. Sine, F. L., The pegmatite dikes of southeastern Ontario: *Canadian Min. Jour.*, vol. 47, no. 7, pp. 169–171, Feb. 12, 1926; vol. 47, no. 10, pp. 237–243, March 5, 1926; vol. 47, no. 11, pp. 257–262, Mar. 12, 1926. Spence, Hugh S., and Carnochan, R. K., The Wilberforce radium occurrence: *Canadian Min. and Met., Bull.* 23, pp. 649–688, 1930. Walker, T. L., and Parsons, A. L., Beryl and associated minerals from Lyndoch township, Renfrew County, Ontario: *Univ. Toronto Studies, Geol. Ser. no.* 24, pp. 12–14, 1927. Walker, T. L., and Parsons, A. L., Apatite, lepidomelane, and associated minerals from Faraday township, Hastings County, Ontario: *Univ. Toronto Studies*, no. 22, pp. 20–25, 1926. Walker, T. L., and Parsons, A. L., Minerals from the new nepheline syenite area, French River, Ontario: *Univ. Toronto Studies*, no. 22, pp. 5–14, 1926. Wilson, M. E., Molybdenite in the lower Ottawa Valley: *Canada Geol. Survey, Summary Rept.*, Part E, pp. 19–44, 1920 (for 1919).

MANITOBA. Principal localities: Southeastern and northwestern (between Wekuska Lake and Saskatchewan line) portions of province. Types: Granite simple and complex, and a few diorite pegmatites in northwestern Manitoba. Phases in complex granite pegmatites are lithium, beryl, tin, molybdenite, and rare earth minerals, all in southeastern Manitoba, and sulphide ore phase in northwestern Manitoba.

REFERENCES: Bruce, E. L., Molybdenite near Falcon Lake, Manitoba: *Canada Geol. Survey, Summary Rept.*, Pt. D, pp. 22–25, 1917. De Lury, J. S., Tin prospects

in Manitoba: *Canadian Min. Jour.*, vol. 50, no. 35, pp. 810-813, 1929. De Lury, J. S., Beryl in Manitoba: *Canadian Min. Jour.*, vol. 51, no. 43, pp. 1015-1018, Oct. 24, 1930. De Lury, J. S., and Ellsworth, H. V., Uraninite from the Huron claim, Winnipeg River area, southeastern Manitoba: *Am. Mineral.*, vol. 16, no. 12, pp. 569-575, 1931. Derry, D. R., The genetic relationships of pegmatites, aplites, and tin veins: *Geol. Mag.*, vol. 68, no. 808, pp. 454-475, 1931. Stockwell, C. H., Geology and mineral deposits of a part of southeastern Manitoba: *Canada Geol. Survey, Mem.* 169, 1932. Wallace, R. C., Relationships in mineral deposits in northwestern Manitoba: *Econ. Geology*, vol. 20, pp. 431-434, 1925. Wright, J. F., Geology and mineral deposits of a part of northwestern Manitoba: *Can. Geol. Survey, Summary Rept.* 1930, Pt. C, pp. 1-124, 1931.

SASKATCHEWAN. Simple granite pegmatites are fairly numerous in parts of northeastern Saskatchewan.

REFERENCE: Wright, J. F., *Canada Geol. Survey, Summary Rept.* 1932, p. 90 C.

BRITISH COLUMBIA. Principal localities: Widely scattered over eastern and southern British Columbia and in northern British Columbia near Fort Grahame and on the coast in the neighborhood of Douglas Channel. Types: Granite simple and complex, monzonite complex, and basic complex. Complex granite pegmatites with a molybdenite phase occur south of Salmo and west of Nelson (Molly mine). A beryl phase is found near Tete Jaune and rare earth minerals occur in a basic pegmatite on Moose Creek, south-east of Leauchoil. A copper sulphide ore phase has been observed in pegmatites on the shores of Douglas Channel and at Copper Mountain in the Yale district. The latter pegmatite is a monzonite in composition.

REFERENCES: Catherinet, Jules, Copper Mountain, British Columbia: *Eng. and Min. Jour.*, vol. 79, no. 3, pp. 125-127, Jan. 19, 1905. Dolmage, Victor, Finlay River district, British Columbia: *Canadian Min. Jour.*, vol. 50, no. 8, pp. 164-168, no. 10, pp. 214-217, 229, 1929. Dolmage, Victor, Coast and islands of British Columbia between Burke and Douglas Channels: *Canada Geol. Survey, Summary Rept.*, Pt. A, pp. 35-37, 1921. Ellsworth, H. V., and Walker, J. F., Knopite and magnetite occurrence, Moose Creek, southeastern British Columbia: *Canada Geol. Survey, Summary Rept.*, Pt. A, 1925.

GREENLAND

Localities: Mainly on south and west coasts. Types: Granite and alkaline syenite. Complex with molybdenite phase near Egedesminde and Sydproven. Rare earth mineral phase present in Julianehaab district (in soda syenite pegmatites) and at Kara Akimgirait (East Greenland) and Kikertak (Upernivik district). Graphite-bearing pegmatites occur on Lango (Long) Island. The

famous cryolite deposit of Ivigtut is considered to be a pegmatite in which the fluorine phase is so strongly developed that cryolite has been substituted for feldspar.

REFERENCES: Baldauf, R., and Beck, R., Ueber das Kryolith-Vorkommen in Grönland: *Zeitschr. prakt. Geol.*, vol. 18, pp. 432-446, 1910. Ball, Sydney, H., The mineral resources of Greenland: *Med. om Groenland*, vol. 63, pp. 1-60, 1922. Gordon, S. H., Mining cryolite in Greenland: *Eng. and Min. Jour.-Press*, vol. 121, pp. 236-240, Feb. 6, 1926.

MEXICO

Localities: Muscovite has been intermittently mined from a number of pegmatites in Lower California and Sonora. Type: Probably granite simple.

GUATEMALA

Localities: Departments of El Quiche and Baja Verapaz. Types: Muscovite pegmatites, probably granite simple.

SOUTH AMERICA

GENERAL REFERENCES: Miller, B. L., and Singewald, J. T., Jr., *Mineral deposits of South America*, New York, 1919. Gerth, H., *Geologie Südamerikas*, Berlin, 1932.

BRAZIL. Principal localities: Scattered through ancient crystalline rocks of Minas Geraes, Bahia, Goyaz, and Sao Paulo. Types: Granite simple and complex. Former are very widespread and have been the source of commercial mica in all four provinces. Complex pegmatites are found in greatest abundance in Minas Geraes and Bahia. A zone crossing the two provinces 600 miles long and 100 miles wide parallel to the coast and about 50 miles inland contains pegmatites with a prominent beryllium phase. Some of the beryl localities are S. Anna de Onca, Glycerio (near Rio de Janeiro), and Esmeralda and Bom Jesus dos Meiros (emeralds). Brazil is a most important tourmaline producer, mainly from pegmatites at Lajao, Minas Geraes. A fluorine phase occurs on the island of Pescaria (south of Rio de Janeiro) and at Piracicabo, Minas Geraes. Gold occurs in pegmatites at Passagem. At the following localities the pegmatites exhibit a radioactive mineral phase: Santa Clara do Pomba, Divino de Ubá, São Sebastião de Correntes, Palmeira de São Jose da Lagoa, São Jose de Brejauba de Ferros.



PLATE II. Distribution of complex acidic pegmatites in South America.

REFERENCES: Branner, J. C., Outlines of the geology of Brazil to accompany the geologic map of Brazil: *Bull. Geol. Soc. America*, vol. 30, pp. 189-338, 1919. Derby, Orville A., On the mineralization of the gold-bearing lode of Passagem, Minas

Geraes, Brazil: *Am. Jour. Sci.*, 4th ser., vol. 32, pp. 185-190, 1911. Fenner, C. N., Radioactive minerals from Divino de Ubá, Brazil: *Am. Jour. Sci.*, 5th ser., vol. 16, pp. 382-391, 1928. Moraes, Luciano J., Beryllium minerals in Brazil: *Econ. Geology*, vol. 28, no. 3, pp. 289-292, 1933.

ARGENTINA. Principal localities: The Sierra von Cordoba and other ranges in the provinces of Cordoba, San Luis, San Juan, Catamarca, and Salta, northwestern Argentina. Types: Mainly granite simple. Complex, with ore mineral (wolframite, molybdenite, and copper sulphide) phase in the Sierra von Cordoba. Tantalite and beryl occur in pegmatite near Quines, San Luis Province.

REFERENCES: Rodenbender, Wilhelm, Die Wolfram-Minen der Sierra von Cordoba in der Argentinischen Republik: *Zeit. für prakt. Geol.*, pp. 409-414, 1894. Kittl, Erwin, Tantalita de Quines (Tantalite from Quines): *Museo Nacional de Historia Natural*, (Buenos Aires), *Anales* 36, pp. 335-342, 1931. Abstract *Annotated Bibliography of Econ. Geology*, vol. 5, p. 1, no. 232.

CHILE. Pre-Cambrian crystalline rocks occur in a long narrow belt along the Chilean coast. Beryl has been reported from the Valparaiso district.

BOLIVIA. Principal locality: Metal mining province of western Bolivia. Type: Granite complex, with tin, tungsten, and lithium phases.

REFERENCES: Ahlfeld, F., Supergene cassiterite in tin veins: *Econ. Geology*, vol. 25, pp. 546-548, Aug. 1930. Ahlfeld, F., Ueber die Verteilung des Wolframs in der bolivianischen Metallprovinz: *Chemie der Erde* (Linck u. Blauck), vol. 7(1), pp. 121-129, 1932. Abstract in *Annotated Bibliography of Econ. Geology*, vol. 5(2), no. 442.

PERU. Muscovite-bearing pegmatites occur in the vicinity of Arequipa, Southern Peru.

COLOMBIA. Localities: near Muzo, and in the southern part of the eastern cordillera. Types: Granite simple, and complex with beryllium (emerald) phase in Muzo district.

REFERENCES: Ball, S. H., The geologic and geographic distribution of precious stones: *Econ. Geology*, vol. 17, pp. 575-602, 1922. Pogue, J. E., The emerald deposits of Muzo, Colombia: *Trans. Am. Inst. Min. Eng.*, vol. 55, pp. 910-934, 1917. Vargas Vasquez, Luis, and Cuervo Araoz, Gabriel, Notes on mica deposits east of Garzon, Huila, Colombia: *Bol. Minas y Petr., Bogota*, vol. 4 (21-22), pp. 338-351, Sept. Oct., 1930. Abstract in *Annotated Bibliography of Econ. Geology*, vol. 4, p. 1, no. 538.

(To be continued)

CRYSTAL STRUCTURE OF COMMON ZOISITE

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Zoisite, $\text{Ca}_2\text{Al}_3(\text{OH})(\text{SiO}_4)_3$, is said by Groth¹ and others to exist in two modifications, orthorhombic and monoclinic. The monoclinic variety, clinozoisite, usually contains some Fe^{+++} in place of Al^{+++} and is then called epidote.

Gossner and Mussnug² have made *x*-ray analyses of zoisite and epidote from the Austrian Tyrol and report zoisite as orthorhombic, $a:b:c = 16.21:5.63:10.08$.

Two dimorphous series are considered to exist.³

α -zoisite	\longleftrightarrow	β -zoisite	orthorhombic
\updownarrow		\updownarrow	
clinozoisite	\longleftrightarrow	epidote	monoclinic

Winchell states that

"more than 5% Fe^{+++} in zoisite seems to favor crystallization in the monoclinic system as epidote. Iron free zoisite has the optic plane parallel to 010 (the cleavage), and normal to 100, while feriferous zoisite (β -zoisite) has the optic plane parallel to 001 (normal to the cleavage), and normal to 100. Iron free zoisite has (+) $2V = 30^\circ$, β -zoisite (+) $2V = 60^\circ$. Between the limits $2V$ passes through zero. $a:b:c = 0.620:1:0.343$."⁴

Zoisite occurs in schists, in igneous rocks as an alteration product of plagioclase feldspars, in impure contact metamorphosed limestones and in quartz veins in altered basic igneous rocks. Winchell states that zoisite is less common than clinozoisite, and iron-bearing zoisite still less common. Some others list zoisite as more common.

Zoisite is said to be clear and transparent only when fresh. Good

¹ Groth, P., *Chemische Kristallographie*, p. 283. W. Englemann, Leipzig, 1908.

² Gossner, B., and Mussnug, F., *Centralblatt für Mineralogie and Geologie*, 1930, A. p. 369.

³ Winchell, N. H., and Winchell, A. N., *Elements of Optical Mineralogy*, Part II, p. 353. John Wiley and Sons, New York, 1927.

⁴ Winchell's notation differs from that of Gossner and this paper by interchange of *a* and *b*, and *b* and *c*.

crystals appear to be rare, and these usually translucent. Most occurrences of the mineral are in massive form.

It is probable that Winchell's data are for fresh zoisite, instead of the common zoisite of rocks. Because there appeared to be a difference, the following work was begun.

The crystals used in this work were from Praegratten, Austria, and therefore represent a fair comparison with Gossner's work. The crystal of zoisite used was about $1 \times 1 \times 2$ mm. and appeared to be orthorhombic. The crystal was translucent and striated both parallel and at angles with prism edges. On completion of the x -ray analysis it was broken up and examined with the petrographic microscope. Fragments showed various degrees of birefringence, no apparent cleavage, and in general were in an unsatisfactory state for microscopic analysis, as is often the case.

Assuming the crystal to be orthorhombic, oscillation measurements were made on three normal axes believed to be crystallographic axes, using both layer line and principal spectrum data. The results obtained are listed in Table 1.

TABLE 1

Axes (orthorhombic)	Axial length A.U.
<i>a</i>	16.30
<i>b</i>	5.60
<i>c</i>	10.21

These results agree with Gossner's, probably within experimental error.

A Laue photograph made with the beam parallel to the orthorhombic *c*-axis showed planes of symmetry parallel to *a*- and *b*-axes, and apparently agreed with the orthorhombic assignment.

Figure 1 shows a Laue photograph with the beam parallel to the orthorhombic *b*-axis. One can assume two planes of symmetry in the reproduction of this photograph as well, in which case one arrives at the same conclusion as Gossner.

Figure 2 shows a Laue diagram of epidote, with the beam parallel to the monoclinic *b*-axis. It is most interesting to note that the symmetry of Figure 1 of zoisite can be exactly duplicated both in the projection and reproduced photograph by a twinning of 2 on 100. Furthermore, epidote is reported as twinning on this face.

Oscillation measurements were made, assuming that the above twinning might have taken place.

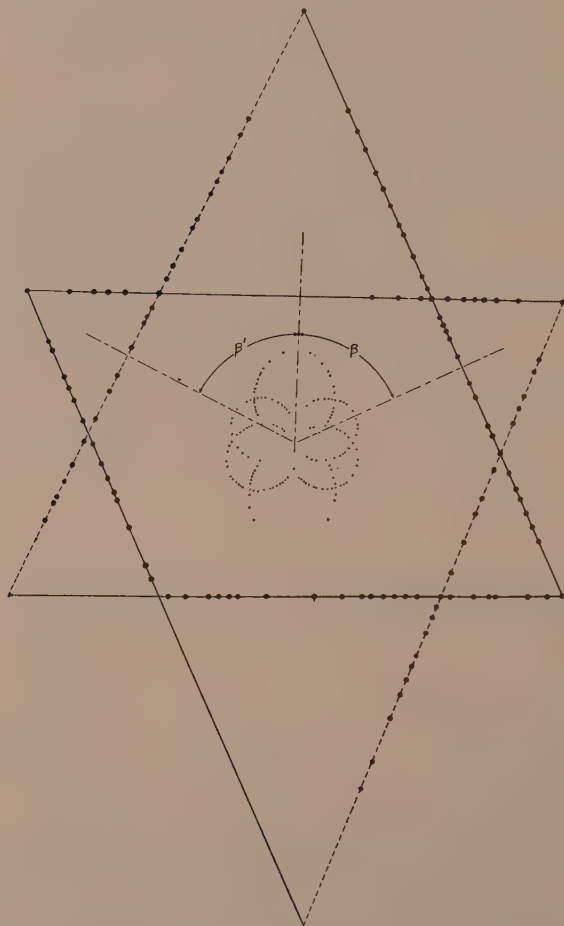


FIG. 1. Gnomonic projection of Zoisite. X-rays parallel to *b*-axis.

Axes (monoclinic)	TABLE 2	
	Axial Length A.U. Common Zoisite	Axial Length A.U. Gossner-Epidote
<i>a</i>	8.92	8.96
<i>b</i>	5.60	5.63
<i>c</i>	10.21	10.20

Figure 3 is a comparison of powder diffraction photographs of epidote and zoisite. It will be noted that line for line the two agree, except for a very slight difference in spacing.

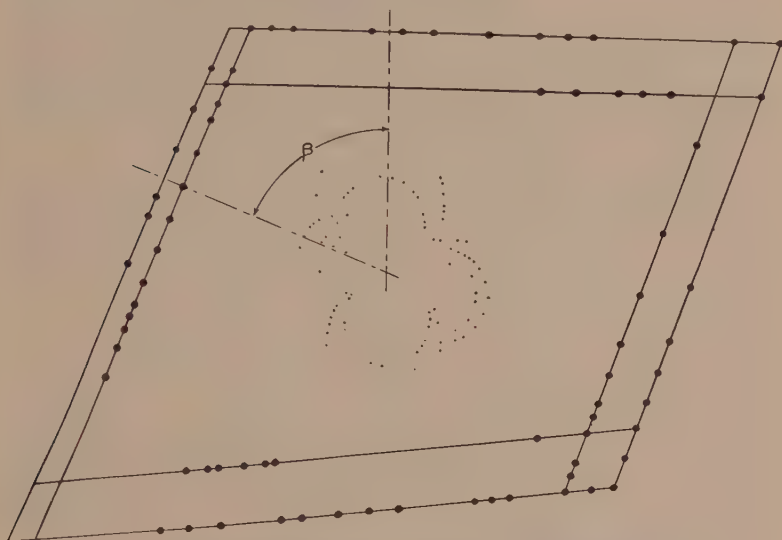


FIG. 2. Gnomonic projection of epidote. X-rays parallel to *b*-axis.

The results of Table 2 compared with Gossner's values for epidote, coupled with Figure 3 and the fact that β and β' of Figure 1 correspond to β for epidote, leave no doubt that the

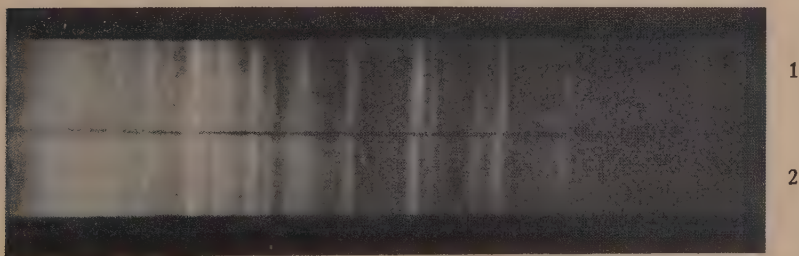


FIG. 3. 1., Zoisite; 2., Epidote.

crystal examined is not orthorhombic but is made up of sub-microscopic multiple twins, or is a mosaic crystal giving an orthorhombic appearance. The relation of pseudo-orthorhombic and

monoclinic axes is the same except that the monoclinic a is inclined to the orthorhombic a -axis.

Since the monoclinic cell is the smaller of the two, and since the measurements are a good check on Gossner's epidote measurements, it is proper to assign this zoisite to the monoclinic system, name it clinozoisite, and apply the data of Table 2 to the unit cell.

The number of molecules per unit cell was calculated. Two mols. of zoisite were found to make up the monoclinic unit cell, corresponding with Gossner's results of two for epidote.

The Laue photograph with x -rays parallel to c can be interpreted as having two planes of symmetry, or a plane in a and c , with b or c a two-fold axis. The only monoclinic space group having this symmetry is the group C_2^h (monoclinic prismatic class) which has a plane of symmetry in a and c , with b a two-fold axis.

The authors are not in a position to state whether Gossner's orthorhombic zoisite was correct or not, and do not seriously question the possibility of transparent zoisite being orthorhombic, but in view of the close agreement of measurements, and the locality of collection it would appear that Gossner's zoisite was the same as that here analyzed, and that he had mistaken the symmetry introduced by twinning for true symmetry.

By interchange of a and b , and b and c , to compare with Winchell's notation, and using the orthorhombic measurements the authors arrive at $a:b:c=0.626:1:0.343$, an interesting comparison with the previously given values. The question arises, "Is fresh transparent zoisite an unstrained multiple twinning of clinozoisite, and the translucent variety merely the result of slight shattering due to a change in conditions?" That is, may not fresh zoisite have all the necessary symmetry for an orthorhombic assignment, yet be more correctly placed as monoclinic, as the translucent zoisite of this paper has been?

It appears to the authors that an investigation of fresh transparent zoisite would be worth while. However, no fresh zoisite is available, and no one seems able to supply it. Likewise other dimorphous series might well be examined more critically with a view to determine whether some pseudo-symmetry might exist.

The fact remains that the translucent variety of zoisite is clinozoisite. It is very possible that the material crystallizes in the orthorhombic form and that the peculiarities mentioned are due to a recrystallization. Probably, when sufficient iron is present,

the stable form crystallizing is monoclinic since epidote shows no signs of recrystallization.

CONCLUSIONS

1. Common translucent zoisite is made up of a mosaic consisting of submicroscopic multiple twins of clinozoisite.

2. Clinozoisite, part of the isomorphous epidote series, has $a:b:c=8.92:5.60:10.21$ and belongs to the space group C_2^h , the unit cell containing two molecules.

3. With (1) in mind fresh transparent zoisite might well be examined by x -rays.

AUSTINITE, A NEW ARSENATE MINERAL, FROM GOLD HILL, UTAH*

LLOYD W. STAPLES, *Stanford University.*

In September, 1933, a suite of specimens collected from an outcrop of the Western Utah Copper Company's orebody at Gold Hill, Utah, was sent to the mineralogical laboratory of Stanford University by Dr. W. R. Landwehr. The material contained well developed crystals of quartz, adamite,¹ and also some minute colorless crystals which proved to be a new mineral. The name *austinite* was chosen for this new mineral in honor of Professor Austin F. Rogers, and in recognition of his many valuable contributions to the science of mineralogy.

Both gold and copper have been found at Gold Hill and about ten years ago scorodite was mined as a source of arsenic. The fact that this occurrence is normal scorodite was shown by Foshag, Berman, and Doggett.² The common minerals and general geology of the district have been discussed by Kemp and Billingsley,³ and by Butler.⁴

GENERAL DESCRIPTION OF AUSTINITE

Austinite occurs in distinct, well developed, orthorhombic crystals of bladed or acicular habit, elongated parallel to the *c*-axis. The mineral occurs in the oxidized zone, where it is found developed on the colloform surfaces of limonite or lining small cavities. It is closely associated with adamite, and it appears to be a later mineral, since in many cases groups of crystals of austinite have been found coating and growing on top of the adamite. A very unusual feature of the occurrence of the austinite is the prevalence of scepter crystals of the type shown in Fig. 1. The reason for this peculiar habit is not known to the author. It is difficult to find doubly terminated crystals, but when the scepter

* Paper presented at the fifteenth annual meeting of the Mineralogical Society of America, Rochester, N. Y., Dec. 27, 1934.

¹ A description of the adamite will be given in a later paper.

² Foshag, W. F., Berman, H., and Doggett, R. A., Scorodite from Gold Hill, Tooele Co., Utah: *Am. Mineral.*, vol. 15, pp. 390-391, 1930.

³ Kemp, J. F., and Billingsley, P., Notes on Gold Hill and Vicinity, Tooele Co., Western Utah: *Econ. Geol.*, vol. 13, pp. 247-274, 1918.

⁴ Butler, B. S., et al, The Ore Deposits of Utah: *U.S.G.S. Prof. Paper* 111, pp. 476-484, 1920.

habit is developed and the "stalk" is very thin, an almost perfectly doubly terminated crystal may be obtained by breaking off the "stalk." The crystals are colorless and have a sub-adamantine luster. The cleavage is good in two directions, parallel to the prism faces $\{110\}$. The average length of the crystals is 0.5 mm. and the maximum is about 1 mm. Because of this minuteness it is difficult to obtain good images with the reflection goniometer from some of the smaller faces.

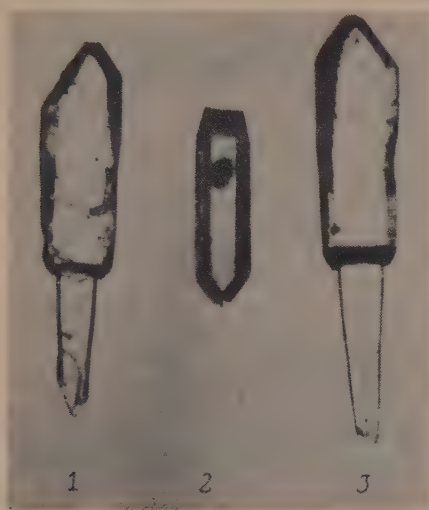


FIG. 1. Crystals of austinite. 1 and 3 are scepter crystals; 2 is doubly terminated, with "stalk" broken off. 1 is a right-handed crystal; 2 and 3 are left-handed. Actual length of 2 is 0.3 mm.

GEOMETRICAL CRYSTALLOGRAPHY

Austinite belongs to the rhombic disphenoidal class ($3A_2$) of the orthorhombic system. The most common forms on the crystals are the rhombic prism $m\{110\}$ and a rhombic disphenoid, either positive $p\{111\}$, or negative $\rho\{\bar{1}\bar{1}1\}$. A few of the crystals are modified by $b\{010\}$ and $q\{011\}$. In addition there are faces, on some of the crystals, of very low slope and from their appearance and the easy solubility of the mineral, it seems probable that they are due to solution. If the crystals are doubly terminated and the prism faces equally developed, the crystals resemble those in Fig. 2. The left drawing in Fig. 2 was made by turning over the

right, and connecting pin holes which had been pricked through at the corners of the latter. This is essentially the same method as that given for enantiomorphous crystals by Rogers.⁵ The most common habit is that shown by crystals 1 and 3 in Fig. 1, where two of the opposite prism faces are wide and the other two are narrow. This gives the crystal a bladed habit. It is interesting to note that on none of the crystals studied were both right-handed and left-handed disphenoids present. Also, it seems from the crystals studied to date that the right-handed ones are more common

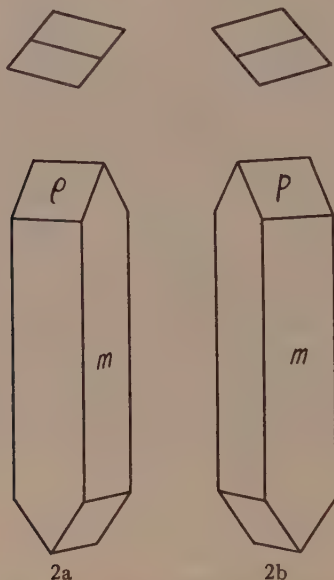


FIG. 2. Left-handed (2a) and right-handed (2b) crystals of austinite with the forms $m\{110\}$, $p\{111\}$, and $\rho\{1\bar{1}1\}$.

than the left-handed. In Fig. 1, crystal 1 is right-handed while crystals 2 and 3 are left-handed.

Because of the scepter habit of most of the crystals it required examination of a great many of them to obtain material suitable for goniometric work. It was finally found possible to obtain crystals that gave good signals from the prism and the rhombic disphenoid faces. Because of the narrowness of the $b\{010\}$ faces, weak signals were obtained, but they were fairly good. The $q\{011\}$

⁵ Rogers, A. F., *Introduction to the Study of the Minerals*, 1st ed., p. 153, 1912.

faces were in all cases too small to give definite signals, so positions of maximum reflection had to be chosen, and the results have an accuracy of only about a half of a degree. The angles measured are tabulated below (Table 1).

TABLE 1

Angle	No. of xls.	No. of meas.	Limits	Average angle (weighted)	Calculated angle
mm''' (110 \wedge 1 $\bar{1}$ 0)	12	54	66°27'–66°45'	* 66°37'	
pp' (111 \wedge 1 $\bar{1}$ 1)	6	30	113 1–113 27	*113 10	
$\rho\rho'$ (1 $\bar{1}$ 1 \wedge 1 $\bar{1}$ 1)	2	10	113 8–113 25	113 12	113°10'
mb (110 \wedge 010)	4	10	56 29–56 44	56 41	56 41½
bq (010 \wedge 011)	6	12	48 50–51 26	49 35	50 14
mp (110 \wedge 111)	6	11	33 27–33 31	33 30	33 25
$m'''p$ (1 $\bar{1}$ 0 \wedge 1 $\bar{1}$ 1)	2	4	33 24–33 28	33 26	33 25
$m'''p$ (1 $\bar{1}$ 0 \wedge 111)	1	8	70 32–70 35	70 34	70 39

The fundamental angles, given with an asterisk in Table 1, lead to the axial ratio:

$$a:b:c=0.657:1:0.832$$

Although great care was taken in the goniometric measurements, it is believed that because of the small size of the crystals, computation of the axial ratio to the fourth place is not warranted. This is in accord with the suggestion of Hey,⁶ who has pointed out the tendency of crystallographers to state their results in a manner indicating unwarranted accuracy.

The angles computed for the unit faces are $100\wedge110=33^{\circ}18\frac{1}{2}'$, $001\wedge101=51^{\circ}42\frac{1}{2}'$, and $001\wedge011=39^{\circ}46'$.

ETCH FIGURES

Crystals of austinite were etched with very dilute HCl (1:6). Etch figures are produced on the rhombic disphenoid in a few seconds, but they are not very distinct. The best etch figures were obtained on the prism faces and this required an immersion in the acid of only three or four minutes for best results. Fig. 3 gives developments of right- and left-handed crystals showing the type of etch figure that is found on each prism face. It would be possible

⁶ Hey, M. H., On the Accuracy of Mineralogical Measurements: *Mineral. Mag.*, vol. 23, pp. 495–496, 1934.

to tell whether the prisms were right- or left-handed by using etch figures, even if the crystals were not terminated. The etch figures confirm the lack of symmetry planes and indicate that the crystals must belong to the class with the symmetry $3A_2$, that is, the rhombic disphenoidal class. Epsomite, goslarite, morenosite, leucophanite, and edingtonite have this same symmetry and possibly sulphur also belongs in this class. Although the rhombic disphenoidal class includes only a few minerals, it is interesting to note that this class is represented by over 400 artificial substances.

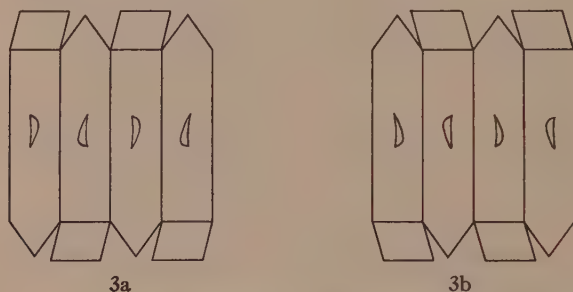


FIG. 3. Etch figures diagrammatically shown on the prism faces of left-handed (3a) and right-handed (3b) crystals of austinite.

SPECIFIC GRAVITY

The specific gravity of austinite is about 4.12. This value was determined by the pycnometer method. Since only 0.166 grams of the material was available for the determination, and furthermore since it was impossible to completely free this material from a small amount of impurities, the gravity determination can only be considered an approximate value.

OPTICAL PROPERTIES

The values obtained for the three principal indices of refraction using a Wratten orange screen (E 22), made by the Eastman Kodak Co., were:

$$n_{\alpha} = 1.759 \pm 0.003, \quad n_{\beta} = 1.763 \pm 0.003, \quad n_{\gamma} = 1.783 \pm 0.003.$$

The maximum double refraction derived from these indices is, $n_{\gamma} - n_{\alpha} = 0.024 \pm 0.006$. The liquids used for the index determinations were made by dissolving sulphur in methylene iodide and although they stood for two months it was considered advisable to check their indices each time when used, since they were found

not to remain absolutely stable. The prism method with the goniometer was used for the index determination of the liquids.

The plane of the optic axes lies parallel to $a\{100\}$ and $a=\beta$, $b=\gamma$, $c=\alpha$. Because of the good prismatic cleavage it was difficult to obtain a random orientation of the cleavage fragments. In order to avoid possible error in the determination of the indices of refraction from this cause, fragments giving desired interference figures were used in the index determinations. Both the crystals and the cleavage fragments are length-fast, or have negative elongation.

The mineral is optically positive, and $2V$ is approximately 47° . This value for the optic axial angle was obtained by using Mallard's method, the constant D for the microscope being obtained from a piece of muscovite with carefully determined $2V$. The value of $2V$ for austinite, calculated from the indices of refraction, checks that obtained by Mallard's method within two degrees.

CHEMICAL COMPOSITION

A preliminary qualitative examination of the crystals was made by microchemical methods. The value of a microchemical examination, where only a small amount of material is available, was clearly shown in this case. By dissolving just one or two of the crystals it was possible to show that the mineral contained zinc and calcium in abundance and that it was an arsenate. The potassium mercuric thiocyanate test was used for zinc, and calcium was shown to be present by precipitating microchemical gypsum ($\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$) with dilute sulphuric acid in the presence of alcohol. The arsenate radical was detected by the AgNO_3 test, and the presence of arsenic was corroborated by H_2S precipitation. The Penfield closed tube test for water was employed on 0.0435 g. of the mineral and indicated a water content of 3.2 per cent. From these preliminary tests it was concluded that the mineral is a basic calcium zinc arsenate.

Austinite is soluble with ease in cold dilute HCl . Due to the ready solubility of the mineral, it proved to be a good subject for study by etch figures.

A complete analysis was made by Dr. R. B. Ellestad of the University of Minnesota Rock Analysis Laboratory on 1.2 grams of carefully selected material. In purifying the material for the analysis, part of the limonite clinging to the grains was dislodged by

means of a needle point, and the rest was taken from the crushed sample by means of a strong electro-magnet. However, in spite of the fact that each minute grain selected for analysis was carefully examined under the microscope, it was impossible to avoid some contamination from quartz and adamite. They are both intimately associated with the austinite and they are difficult to distinguish from it in such small aggregates. The quartz did not seriously interfere in the analysis, since it was insoluble and was just reported as residue. The analysis of the austinite is given in column I.

ANALYSIS OF AUSTINITE BY R. B. ELLESTAD

	I	II	III	IV	V	VI
CaO	19.2	.342	$2 \times .171$.342	$= .342$	$= 2 \times .171$
ZnO	32.5	.399	$2 \times .199$	$.399 - .057$	$= .342$	$= 2 \times .171$
As ₂ O ₅	42.7	.186	$1 \times .186$	$.186 - .014$	$= .172$	$= 1 \times .172$
P ₂ O ₅	0.1					
H ₂ O	3.6	.200	$1 \times .200$	$.200 - .014$	$= .186$	$= 1 \times .186$
Residue	2.4					
V ₂ O ₅	None					
Total	100.5					

Column II represents the molecular ratios, with the small amount of P₂O₅ added to the As₂O₅. From column III it is evident that the analyzed sample closely approaches the composition 2CaO · 2ZnO · As₂O₅ · H₂O. A microscopic examination of part of the sample, using index liquids, indicated the presence of a small amount of adamite. We, therefore, may assume that the excess of ZnO over CaO shown in the analysis is due to the slight admixture of adamite. If we subtract this excess of ZnO and one-fourth this amount of As₂O₅ and H₂O, to correspond to the formula of adamite (4ZnO · As₂O₅ · H₂O) as in column IV, we have the figures of column V and their equivalent in column VI. The resultant molecular ratios given in column VI leave little doubt concerning the correctness of the formula 2CaO · 2ZnO · As₂O₅ · H₂O or CaZn(OH)AsO₄. The theoretical percentages of the oxides for this formula are: CaO = 21.45%, ZnO = 31.13, As₂O₅ = 43.97 and H₂O = 3.45.

From the values obtained in column III it might be concluded that austinite is either a double salt or an isomorphous mixture. Zinc and calcium do not seem to be found often replacing each other

in minerals, and the exact 1:1 ratio of the CaO and ZnO, when allowance is made for the contamination of the sample by adamite, indicates that austinite is undoubtedly a double salt.

The mineral austinite is closely related chemically to the members of the olivenite group. However, that it does not belong to the group is shown by its lower symmetry, the different optical orientation and the difference in axial ratios. At present it cannot be placed in any known mineral group. It is the first arsenate of zinc and calcium to be described as a mineral⁷ and it is believed to be a basic arsenate with the formula CaZn(OH)AsO_4 .

ACKNOWLEDGMENTS

The author wishes to express his thanks and acknowledge his indebtedness for the many facilities placed at his disposal, as well as for the many valuable suggestions offered by Professor Austin F. Rogers. Thanks are also due to Dr. W. R. Landwehr for the material upon which this study was made.

SUMMARY

The following is a tabulation of the properties of austinite.

Chemical formula: CaZn(OH)AsO_4

Crystal system and class: orthorhombic, rhombic disphenoidal class ($3A_2$).

Habit: prismatic.

Forms: $m\{110\}$, $p\{111\}$, $\rho\{1\bar{1}1\}$, $b\{010\}$, $q\{011\}$.

Axial ratio: $a:b:c=0.657:1:0.832$.

Cleavage: parallel to $m\{110\}$.

Specific Gravity: ca. 4.12

Optical character: positive.

Optical orientation: $a=\beta$, $b=\gamma$, $c=\alpha$. Axial plane = $\{100\}$.

Optic axial angle: $2V=\text{ca}:47^\circ$.

Indices of refraction: $n_\alpha=1.759\pm0.003$, $n_\beta=1.763\pm0.003$, $n_\gamma=1.783\pm0.003$.

Max. double refraction: 0.024 ± 0.006

⁷ The name *brickerite* has been given to an arsenate of zinc and calcium from Bolivia, but in the absence of an adequate description the name is a *nomen nudum* and has no standing. The mineral is briefly mentioned by Ahlfeld in *Neues Jahrb. Mineral., Abt. A, Beil.-Band*, **66**, p. 44, 1932, who said that it would be described by its discoverer, Dr. Barrande-Hesse.

A CONTACT METAMORPHIC ZONE FROM THE LITTLE BELT MOUNTAINS, MONTANA

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1. INTRODUCTION AND ACKNOWLEDGMENTS

The contact zone described in this paper is situated some 10 miles south of the town of Neihart in the Little Belt Mountains of central Montana. The material examined was collected during the summer of 1933 by Professor E. S. Larsen, Jr., from a cutting on the new White Sulphur Springs-Neihart automobile road. From Weed and Pirsson's account of the area (1)¹ it seems almost certain that the intruded limestone of the contact zone is a member of the Cambrian Barker formation while the igneous rock is probably one of the small bodies mapped as "diabase, basalt, minette, vogesite or kersantite."

The present account is limited by the material available and is not intended to be anything more than a preliminary description of an area which appears likely to repay more detailed study. The author's thanks are due to Professor Larsen for affording him the opportunity of carrying out the work and for much kind assistance and criticism. He is also indebted to Professor L. C. Graton for allowing him to have polished surfaces of opaque minerals made by his special process, and to Dr. K. C. Dunham for help in the identification of the opaque minerals.

2. THE IGNEOUS ROCK AND ENDOMORPHIC CONTACT ZONE

The igneous rock is a calc-alkaline gabbro whose essential constituents are abundant pyroxene, biotite and labradorite together with serpentine and talc pseudomorphs after olivine.

¹ See list of references at end.

The pyroxene is a colourless augite occurring in rather irregular fragments. In many cases the smaller grains are disposed in typical reaction relation round the margins of the olivine pseudomorphs. The latter have the unmistakable form of olivine prisms capped by steep bipyramids, but it is rarely that any of the original mineral is left in the centre of the replacing talc and serpentine. Brown biotite is plentiful in long fibrous laths, giving a lamprophyric appearance to the rock in the hand specimen, and there are smaller amounts of a green chlorite approximating to delessite. These minerals are set in a groundmass of irregular and often somewhat cloudy plagioclase, with a composition—as determined by measurement of the indices—of $\text{Ab}_{35}\text{An}_{65}$.

Among the accessory minerals are blebs of calcite, abundant needles of apatite, commonly with a central core of inclusions, epidote, blue to colourless anatase, magnetite and pyrrhotite often partially altered to limonite.

Micrometric analysis gave the proportions of the various constituents as:

Labradorite	35.5%
Biotite	25.1
Serpentine and talc (after olivine)	19.7
Augite	13.1
Calcite	3.5
Other constituents	3.1

which according to Johannsen's new classification (2) determines the rock as a melagabbro with the symbol 3312 P.

Where the igneous rock near the contact has itself undergone metamorphism the most striking change is in the composition of the feldspar which is entirely orthoclase. Pyroxene is considerably more abundant than in the unaltered rock and biotite much scarcer. Any traces of the original olivine have completely disappeared and there has developed in considerable quantity a green, faintly pleochroic mineral with moderate birefringence and a poorly developed spherulitic structure which is referred to antigorite.

The replacement of the labradorite by orthoclase can only be regarded as due to the action of the same hydrothermal solutions that effected the metamorphism of the surrounding sediments. If we accept B. S. Butler's suggestion (3) that hydrothermal solutions are essentially controlled by the principles of Bowen's reaction series and that hydrothermal processes are in fact the logical

extension of such a series, the replacement of labradorite by orthoclase becomes readily explicable. According to Butler, "In the formation of orthoclase . . . the composition of both the rock and the altering solutions would seem to be controlling factors." If K_2O was present in sufficient quantities, orthoclase would tend to form; while if potash was scarce, sericite with the lower $K_2O:Al_2O_3$ ratio would result. Apart from the normal concentration of K_2O in the residual liquid, the abundant biotite in the unaltered igneous rock provides a potential source. Biotite being low in the reaction series would be one of the first minerals to react with or dissolve in the hydrothermal solutions; and that this has actually happened is suggested by the relative scarcity of biotite in the endomorphic contact zone. Possibly the supply of CaO (and to a less extent Na_2O) liberated from the plagioclase was partly responsible for the increase in the amount of pyroxene.

3. THE ZONE OF DARK SILICATES

Petrography.

The altered igneous rock of the endomorphic contact zone passes out gradually into what Larsen (4) has called the zone of dark silicates. In the hand specimen the rock from this zone often resembles the gabbro, but its texture is very variable and in some cases porphyritic pyroxene can be seen with the unaided eye. The following is a list of the minerals recorded in approximate order of abundance:

Pyroxene	Sphene	Thomsonite
Prehnite	Ripidolite	Pyrrhotite
Calcite	Sericite	Pyrite
Orthoclase	Phlogopite	Limonite
Garnet	Biotite	Magnetite
Epidote	Actinolite	Sphalerite
Gehlenite	Apatite	Chalcopyrite
Merwinite	Vesuvianite	Hematite
	Chrysotile	

The typical mineral assemblage is a pyroxene-prehnite-calcite one (illustrated in Fig. 1). Pyroxene is generally the dominant mineral, almost colourless except for a narrow green border, in large hemihedral crystals up to 3 mm. in length. It is frequently zoned and shows the strong dispersion ($r > v$), which is usually associated with titaniferous augite—a feature which serves to dis-

tinguish it from the pyroxene of the igneous rock. Locally it is altered to a green chloritic mineral optically negative with very small $2V$, almost zero birefringence and mean index 1.625^2 , agreeing with the data for ripidolite. In other cases it is replaced by a fibrous uralitic hornblende.

The abundance of prehnite is one of the chief characteristics of this suite of rocks. Its optical properties are extremely variable and anomalous characteristics such as abnormal interference

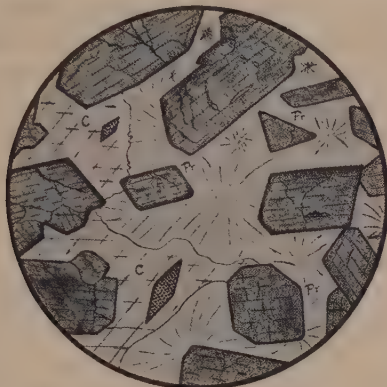


FIG. 1. Zone of dark silicates: pyroxene (stippled) and little sphene set in a groundmass of prehnite (Pr) and calcite (c). $\times 12$.

colours, incomplete extinction and lamellar twinning were commonly observed. Two specimens gave the following data:

(a)	(b)
Biaxial positive	Biaxial positive
disp. $r > v$ strong	disp. absent or very weak
$2V = 40^\circ$	$2V = 65^\circ$
$\alpha = 1.627$	$\alpha = 1.614$
$\beta = 1.629$	$\beta = 1.621$
$\gamma = 1.648$	$\gamma = 1.641$

Prehnite was clearly one of the latest minerals to form and occurs commonly in radiating aggregates in an interstitial relation to the pyroxene, replacing the other constituents of the rock. In some cases the replacement is complete and nothing but prehnite is left, in others orthoclase and calcite in various stages of alteration

² All indices quoted are $\pm .003$.

remain. More rarely the pyroxene has also been attacked and consists of a hollow shell surrounding a radiating mass of prehnite. Less commonly thomsonite is associated with the prehnite in similar aggregates.

Some sections show a considerable amount of still unaltered feldspar, optically negative with $\beta = 1.521$ and a small optic axial angle. The habit varies from irregular masses interstitial to the pyroxene, through broad laths, to an imperfect radiating structure.

A colourless to pale brown birefracting garnet with sectorial twinning is commonly associated with the pyroxene. Optically it is biaxial positive with large $2V$, varying from about 75° to nearly 90° , and dispersion $r > v$ strong. Perhaps on account of its pronounced zoning the indices are very variable: the maximum and minimum limits of β were determined as 1.784 and 1.756. Birefringence is of the order of .012.

Among the minor constituents sphene, apatite and a yellow-green epidote are conspicuous. Study of polished sections shows that a variety of ore minerals are present though never in any great quantity. They are chiefly sulphides apparently of late formation and include chalcopyrite surrounded and replaced by sphalerite, and pyrite and pyrrhotite altering to limonite. The pyrite has been most susceptible to secondary attack and is everywhere seen as cores and imbedded in banded limonite, in which thin hematite layers can be distinguished. The chalcopyrite appears to have been protected from alteration by its enveloping sphalerite. The primary minerals occur in discrete grains scattered through the rock so that the relations between them are not evident.

A distinct facies of the rock consists essentially of merwinite and melilite with small amounts of prehnite, calcite and vesuvianite: in the hand specimen it is rather lighter in colour than the typical dark silicate rock and in some ways appears intermediate between the light and dark zones. The merwinite shows the typical polysynthetic twinning, is optically positive with $\alpha = 1.710$, $\beta = 1.712$, $\gamma = 1.718$ and $2V$ (calculated from the indices) $= 70^\circ$. It occurs in irregular grains set in a matrix of melilite (gehlenite) with low birefringence, negative sign and indices $\epsilon = 1.660$, $\omega = 1.665$. Locally both these minerals are cut by thin veins of merwinite with a little calcite and vesuvianite, suggesting that the latter had a relatively long period of formation, an earlier generation crystallizing before the gehlenite while a later generation succeeded it.

Paragenesis.

The order of deposition of the principle minerals, so far as could be determined from the sections examined is summarized in Table 1. Lack of knowledge of the exact nature of the unaltered country rock renders it impossible to judge to what extent fresh material was introduced across the contact during metamorphism. It appears, however, that two well-marked stages must be recognized:

(1) Formation of orthoclase and pyroxene by the agency of hydrothermal solutions.

(2) Replacement of orthoclase, calcite and to some extent pyroxene by prehnite with a little thomsonite.

TABLE 1. MINERAL SEQUENCE IN DARK SILICATE ZONE.

Pyroxene	—————			
Sphene	—————			
Epidote	—————			
Orthoclase		—————		
Merwinite			—————	
Gehlenite			—————	
Calcite		—————	—————	
Garnet			—————	
Sulphides				—————
Prehnite				—————
Thomsonite				—————

4. THE ZONE OF LIGHT SILICATES

Petrography.

Specimens from this zone are much more uniform in appearance and texture than those from the zone of dark silicates and show less variety in the suite of minerals present. These minerals may be conveniently tabulated together:

Calcite	Gehlenite	Limonite
Vesuvianite	Sericite	Magnetite
Garnet	Epidote	Scawtite
Wollastonite	Pyrrhotite	Okenite?

Vesuvianite, calcite and garnet are the commonest constituents and much of the rock consists entirely of these three minerals. Frequently vesuvianite and calcite show a graphic texture, irregular angular fragments of calcite being surrounded by vesuvianite. The calcite extinguishes simultaneously over wide areas, and there seems little doubt that it has been replaced by the vesuvianite: locally it has a fibrous character. Vesuvianite and garnet are often

closely associated and, as much of the garnet is not completely isotropic, the two may be difficult to distinguish in thin section though the garnet has usually a distinctly higher index. The vesuvianite is optically positive with $\omega = 1.718$ and $\epsilon = 1.723$; the garnet has approximately $n = 1.765$ which agrees more closely with the index for hessonite than for grossularite.

Where wollastonite occurs it is in the form of irregular laths usually imbedded in and completely surrounded by vesuvianite: in some cases it has been partially replaced along the cleavages by calcite. In addition there are small amounts of a finely fibrous pale brown mineral with very low birefringence and mean index about 1.513 which is tentatively referred to okenite.

A distinctive variety of the rock is characterized by gehlenite and scawtite. The former occurs in large square or rectangular sections of weak birefringence, set in an apparently isotropic groundmass so discoloured and altered that its original composition is quite undistinguishable. The scawtite forms small laths optically positive, $\alpha = 1.603$, $\beta = 1.609$, $\gamma = 1.618$, $2V = 78^\circ$, presumably monoclinic with $Y = b$ and $Z \wedge c = 30^\circ$. The data thus agrees fairly satisfactorily with that recorded by Tilley (5) though the birefringence is somewhat weaker. There is no direct confirmation of Tilley's observation that it results from the alteration of gehlenite, but all the sections yielding scawtite also contained gehlenite. A thin 2 mm. dark-coloured vein cutting the gehlenite-scawtite-vesuvianite-calcite rock is illustrated in Fig. 2. On either side the vein is bordered by a solid mass of garnet some 0.2 mm. thick: the center of the vein consists of calcite, garnet, pyrrhotite alternating to limonite and a light brown fibrous mineral including small laths of scawtite. The fibrous mineral would not yield any evidence as to sign or even its uniaxial or biaxial character. The individual fibres extinguish straight and have positive elongation, the mean index is approximately 1.580 and birefringence of the order of .010. Possibly it may be xonotlite but in the absence of better data, judgment is suspended and it will for the present be described as mineral x .

The junction between the zones of light and dark silicates is in many cases surprisingly sharp. In one thin section of the contact it can be seen that the large pyroxene crystals of the dark zone have been partially replaced by the vesuvianite and calcite of the light zone. The line of junction passes quite impartially through pyroxene and groundmass alike, and there can be no doubt that the dark silicates are the earlier and have been replaced by the

light. In other cases the contact is more gradual and the pyroxenes become progressively more irregular in form and more corroded round the margins as the light silicate zone is approached.

Paragenesis.

Table 2 gives the observed mineral sequence in this zone. With the exception of the oxides and sulphides of iron the minerals of this zone are almost exclusively aluminosilicates of calcium with only minor amounts of magnesium, iron, potash, etc. Again one can only speculate as to the amount of material introduced by

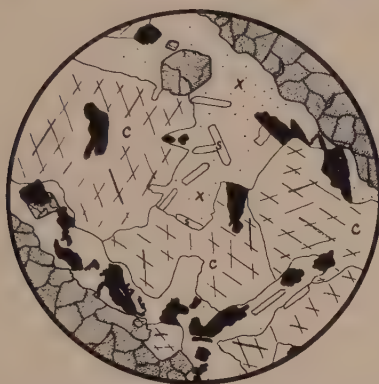


FIG. 2 Vein in zone of light silicates: garnet (stippled), calcite (c) and pyrrhotite (black) with ?xonotlite (x) enclosing laths of scawtite (s). $\times 27$.

hydrothermal solutions and the general conditions at the time of formation. Merwin (6) as a result of laboratory experiments on birefracting garnets from the Kassin Peninsula, Alaska, has found that these become isotropic when heated to 800°C ., and do not readily resume their original nature on cooling. Wright has put this forward as evidence of the contact deposits containing the garnet having been formed at a temperature below 800°C ., but in the present state of our knowledge regarding the mineral it is doubtful if much importance can be attached to its presence.

TABLE 2. MINERAL SEQUENCE IN LIGHT SILICATE ZONE.

Gehlenite	_____						
Wollastonite		_____					
Scawtite			_____				
Calcite	_____						
Garnet			_____				
Vesuvianite				_____			
Pyrrhotite					_____		
Limonite						_____	

5. COMPARISON WITH OTHER AREAS

As has been already inferred, the contact zone resembles in many essential details those described by Larsen and Hess in connection with the tungsten deposits of the United States (4). The most notable difference in the mineral assemblage of the Little Belt rocks is the abundance of prehnite. Harker (7) mentions "prehnitisation" as a common feature of hydrothermal contact zones, and figures somewhat similar rocks, in which prehnite has replaced the earlier minerals, from the Braemar district of Scotland.

The mineral scawtite has hitherto only been recorded from the contact zone at Scawt Hill, Northern Ireland (5), which has some points of resemblance to the Little Belt zone. The mineral assemblage of the latter, however, appears to be intermediate between the (high temperature) spurrite-larnite-merwinite-gehlenite assemblage of Scawt Hill and what Tilley refers to as the more normal (low temperature) diopside-wollastonite-grossular-calcite suite (8). Presumably the temperature of formation was intermediate between these two extremes.

Merwinite has been previously recorded from Scawt Hill (8), Crestmore, California (9), and Velardeña, Mexico (10). In each case it is associated with gehlenite and spurrite: the latter a mineral not so far recorded from the Little Belt but which may possibly be revealed by a further study.

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NOTES AND NEWS

DESCRIPTION OF AN ABNORMAL SURFACE STRUCTURE OF A CRYSTALLINE QUARTZ LENS

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ABSTRACT

An investigation of the cause of an unusual background effect on some photomicrographs taken with an ultra-violet microscope showed that the effect was caused by stepwise discontinuities of the convex surface of the bottom element of the particular crystalline quartz ocular used.

In the course of making some photomicrographs by the use of an ultra-violet microscope an unusual background effect on the finished negative was noticed. This consisted of a series of zig-zag lines, roughly parallel to each other, covering closely the whole field. Figure 1 shows this effect clearly. After checking through the optical system, the cause was isolated in a particular 7X crystalline quartz ocular used at the time of making these photomicrographs.¹

With the cause of this background effect found to be in the ocular, its location was placed as at the bottom lens element, that being the only place it could be sufficiently in focus to be seen clearly without the use of an auxiliary lens. On inspecting the convex surface with incident illumination and the lens tilted so that the reflection of the light source was visible, surface irregularities were seen through a 10X magnifier. The shape of these irregularities is shown in figures 2 and 3. Referring to figure 1 again it will be noticed that these irregularities cover the whole surface in a rather regular pattern.

Although figures 2 and 3 give some idea of the relief of this formation a more complete inspection was necessary. The particular lens element was mounted on a universal stage under a binocular microscope.² With this arrangement, it was possible to study the third dimensional character of the discontinuities. This was

¹ While isolating the cause of these lines it was found that the type of illumination was very important. The beam of light used had to be reasonably free from "skew" rays, i.e., had to consist of central illumination. This condition obtained in the ultra-violet microscope.

² Twin lamps were placed in such position that a lamp reflection from the convex surface was visible in the center of the field of each ocular of the binocular microscope.

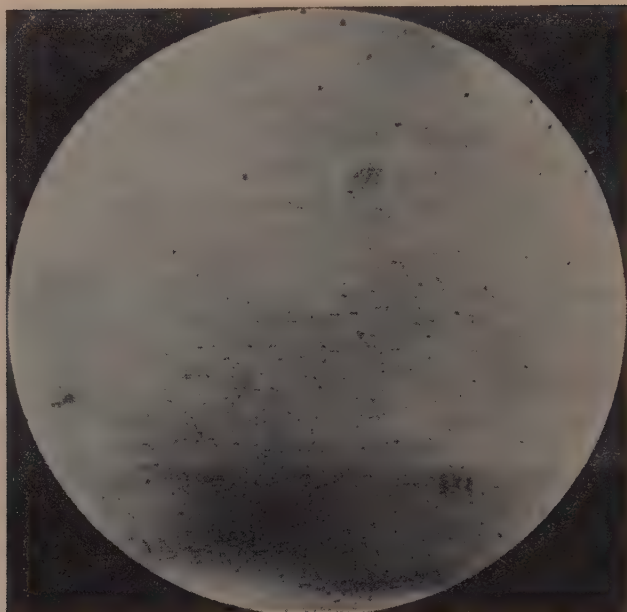


FIG. 1. Made with the ocular in its usual place in the microscope tube and the negative exposed as though making a photomicrograph with the use of illumination through a substage condenser. The light source consisted of a concentrated filament lamp focused at infinity.

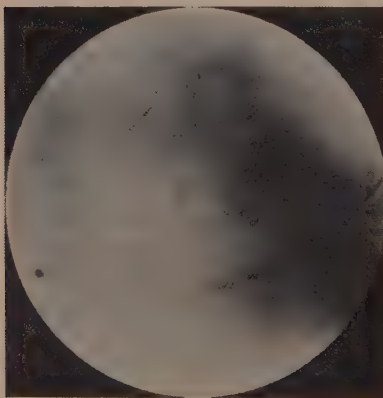


FIG. 2

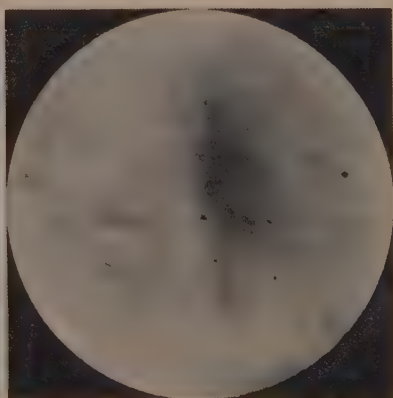


FIG. 3

Made with the lens tilted on the stage at such an angle that the image of the reflection of the lamp used in incident illumination filled the field of the ocular. Light from a condensed filament lamp was focused on the surface being photographed. Magnification 63X.

determined by its appearance to be a step and not a groove. Revolving the stage 180° changed the character of the image as it should for a step but not for a groove. As a check on this and to show the direction of the steps a traverse of the surface was made starting at one edge and passing across to the opposite edge in a direction at right angles to the general line of the zig-zags. Each step was tested by raising the microscope and observing the direction of movement of the "Becke-like" line according to the method of Short.³ The conditions of reviewing each step were identical and in each case the bright line moved in the same direction indicating

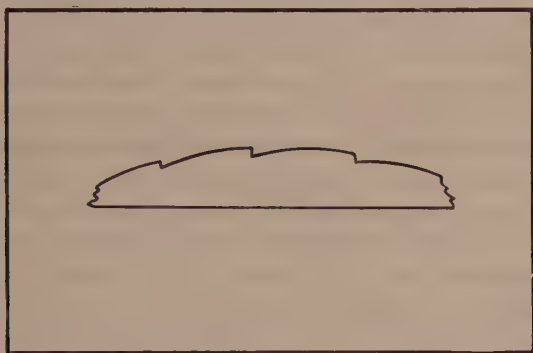


Fig. 4. Cross section of lens showing step-wise discontinuities.

that each step was in the same direction as every other step. Another check was made by repeating the operation on some of the steps with the stage and lens rotated 180° when the steps were again found to be all in the same direction and the reverse of that observed before being rotated. It should be noticed also that figure 1 shows all the lines as bright on the same side. From this it was concluded that the surface was as indicated by figure 4.

Additional data of an optical nature were obtained. By means of a petrographic microscope an optic axis figure was obtained and showed that the axis of the lens did not quite coincide with the optic axis. From observations both with convergent and parallel polarized light the crystal behaved as if quite normal and single and showed, as far as could be ascertained, an absence of twinning.

³ Short, M. N., Microscopic Determination of the Ore Minerals: *U.S.G.S. Bull.* 825, p. 37.

A possible explanation of these discontinuities is seen in the *lineage structure* of a crystal as described by Buerger.^{4,5} This *lineage structure* is present in quartz crystals but just how the grinding of the lens would produce this irregularity is not clearly apparent to the writer although the zone of weakness caused by this structure would produce a location for these discontinuities. Measurements of the dimensions of the spacings of the steps show them to be of the order of magnitude of 0.1 mm. both between adjacent lines and between zig-zags along separate lines. These measurements agree somewhat with the dimensions of "Lineages."⁵

A combination of causes is the probable reason for these steps. It is probable that the blank lens was cut from an improper position, and perhaps from a physically imperfect crystal. It is possible also that the grinding of the lens might have been imperfect by performed in that instead of the proper random directions of stroking, the strokes might have been at least approximately unidirectional in character. Such a condition of grinding acting on the zones of weakness produced by "lineage boundaries" might result in action similar to that performed by glaciers passing over firmly anchored boulders or projecting rock masses, resulting in a smooth curve on the side of approach and a sharp step downward on the lee side.

Before concluding the author wishes to acknowledge the generous help given him by Prof. M. J. Buerger in supplying crystallographic data and information.

DISCUSSION OF THE PAPER "HEAVY MINERALS IN THE SYENITES OF PLEASANT MOUNTAIN, MAINE"¹

RALPH W. MARSDEN, *University of Wisconsin.*

During the course of a study of a syenite stock W. F. Jenks examined the heavy minerals for the purpose of determining the characteristic heavy minerals of each syenite type, the variations in heavy minerals, the degree of constancy within a rock type, and the usefulness of this method of work in the correlation of

⁴ Buerger, M. J., The Significance of "Block Structure" in Crystals: *Am. Mineral.*, vol. 17, pp. 177-191, 1932.

⁵ Buerger, M. J., The Lineage Structure of Crystals: *Zeit. Krist.*, vol. 89, pp. 195-220, 1934.

¹ Jenks, W. F., Heavy Minerals in the Syenites of Pleasant Mountain, Maine: *Am. Mineral.*, vol. 19, pp. 476-479, 1934.

doubtful members. In conclusion he states, "As indexes of rock types the heavy accessories are practically useless. Not only do the relative and absolute proportions of the minerals vary almost as much within a rock type as within the stock as a whole, but the crystal habit and color are in addition practically invariant." In other words Jenks finds that he is unable to distinguish the seven phases of the Pleasant Mountain syenite by heavy mineral methods, hence the methods are useless.

The results obtained by Jenks are in accordance with the underlying principle of heavy mineral work, for the data point to a constancy of the heavy accessory minerals within the syenite stock, even though there is a marked macroscopic change in rock type. The general presentation of results and the lack of detailed study of the various rock types prevent the statement of this as an established fact.

The problem which Jenks attempts to solve by heavy accessory mineral methods is the distinction of phases of the same stock, not the recognition of masses of different ages, or even isolated bodies derived from the same magma. This problem is, to some extent, comparable to the distinction of the assemblages of the Dartmoor and Falmouth granites of England,^{2,3} where the assemblages of the two rocks are very similar even though these masses are separated by 55 miles. In order to distinguish the assemblages of these bodies a detailed study was necessary, which entailed large separations in order to obtain the rare species present. Even then the diagnostic characteristics used included variations in color and crystal habit. Only a slight difference in the accessory minerals would be anticipated in the case of a single stock. The work of Jenks indicates that the accessory mineral variation within the Pleasant Mountain syenite is too slight to be recognized by the methods used.

Jenks states that there are variations in the relative and absolute amounts of the accessory minerals, both within a rock type and the stock as a whole, but no change in color or crystal habit of the minerals. In his investigation he includes the mafic minerals, augite, hornblende, and biotite, with the heavy accessories and makes

² Ghosh, P. K., The Mineral Assemblage of the Falmouth Granite (Cornwall): *Proc. Geol. Assoc.*, vol. 39, pp. 332-338, 1928.

³ Brammall, A., Dartmoor Detritals; A Study in Provenance: *Proc. Geol. Assoc.*, vol. 39, pp. 27-48, 1928.

comparisons of relative and absolute amounts of accessory minerals present with augite, hornblende, and biotite included in the computations. In general usage they are not included with the heavy accessories even though they are heavy minerals.^{4,5} The mafic minerals should be excluded from consideration in the study and correlation of igneous rocks by heavy accessory mineral methods, because of their known variations within a rock type^{6,7} and their abundance in most cases, as compared to the amounts of minor accessories. These mafic minerals comprise as much as 95 per cent of the heavy minerals in the Pleasant Mountain syenite, and a variation in the amount present was recognized within the stock. The inclusion of these minerals with the heavy accessories would and does obliterate the true accessory minerals to such an extent that the variation in percentage recognized might well be confined to the variation of augite, hornblende, and biotite.

Jenks brings out clearly, that in so far as studied, the true accessory minerals are constant throughout the stock. He states, "Magnetite, apatite, titanite, and zircon were accessories in every sample examined. The only additional accessory is rare allanite, . . . from the analcite syenite. In every rock but the analcite syenite the relative and absolute percentages of apatite, titanite and zircon remain fairly constant." In the analcite syenite where a variation in the relative and absolute amounts of accessories was found, the apatite-zircon ratio was the same as in the other rock types; about three to one, and with no change in color or crystal habit, but there was a variation in the amount of titanite. Whether this latter variation is a result of the mafic minerals or inherent in the rock is not made clear. These results are shown in his Table I in which the accessory minerals are given as abundant, very common, common, scarce, and rare; such statements make comparison practically impossible, particularly so since there are no other indications of relative abundance. In several rock types three out of four species present are listed as abundant, with the

⁴ Johannsen, A., *Petrography*, vol. 1, p. 28.

⁵ Wells, A. K., *The Heavy Mineral Correlation of Intrusive Igneous Rocks: Geol. Mag.*, vol. 68, pp. 258-259, 1931.

⁶ Lund, R. J., *Differentiation in the Cape Spencer Flow: Am. Mineral.*, vol. 15, pp. 245-248, 1930.

⁷ Groves, A. W., *The Heavy Mineral Suites and Correlation of the Granites of Northern Brittany, the Channel Islands, and the Cotentin: Geol. Mag.*, vol. 67, Table p. 232, 1930.

remaining one very common. The apatite-zircon ratio is not shown. The presentation of mineral frequency as percentages, now in general use, is far more satisfactory than methods based on estimation. There are errors even when accurate mineral counts are used, but the mineral frequency is presented in a form where the relationship can be readily seen and interpreted.⁸

The Pleasant Mountain syenite, in so far as studied, is another example of the constancy of accessory minerals within a single igneous mass, and a detailed study should give additional support to this basic principle of accessory mineral work. The variations indicated are not in the heavy accessories, but in the mafic minerals, which were included with the heavy accessory minerals. The problem attempted by Jenks was the distinction of types of the same mass, where only a slight difference in accessory minerals would be expected, and a detailed study would be necessary to determine these differences.

⁸ Dryden, A. L., Accuracy in Percentage Representation of Heavy Mineral Frequencies: *Proc. Nat. Acad. Sci.*, vol. 17, pp. 233-238, 1931.

PROCEEDINGS OF SOCIETIES

PHILADELPHIA MINERALOGICAL SOCIETY

Academy of Natural Sciences of Philadelphia, June 7, 1934.

Vice-president Arndt presided at a stated meeting, with 50 members and 35 visitors present. Professor Frederick Oldach addressed the society on "The Cornwall Ore-body." Specimens were exhibited.

The secretary presented a report of the Cornwall trip on May 20th, which produced magnetite, andradite, pyrite, calcite, serpentine, copper, and in the micropegmatite: titanite, epidote, quartz, microcline, apatite. Other trips reported were: by Alexander Fleming, Jr., Blue Ball, Lancaster County (calcite and pink dolomite); Morrell Biernbaum, Black Lake area, Canada (chromite, garnet, diopside); Mr. Toothaker exhibited obsidian from Oregon.

Academy of Natural Sciences of Philadelphia, September 6, 1934.

Vice-president Arndt presided at a stated meeting; 40 members and 18 visitors were present.

The following summer trips were reported: Dr. Baldwin Lucke, Bad Lands, South Dakota, (sand-calcite crystals); John Vanartsdalen, Montclair, N.J., (smoky quartz crystals); Leonard A. Morgan, Clay Center, Ohio, (celestite crystals from the dumps); William Hunt, Henderson station, Pa., (limonite geode, "rattle box"); William Knabe, Pensauken, N.J., (limonite pipes); Byers, Pa., (graphite); Blue Ball, Lancaster County, Pa., (calcite); Jones Mine, Berks County, Pa., (chrysocolla); William Knabe, Charles R. Toothaker, and Samuel G. Gordon, Amelia, Va., (amazonstone, beryl, topaz, tantalite, microlite, albite); Roseland, Va., (rutile and blue quartz); Cockeysville, Md., (pyrite, tremolite, tourmaline, phlogopite); Wood's Chrome Mine, Lancaster County, Pa., (brucite and chromite from dumps); Louis Moyd, Jones Mine, Berks County, Pa., (aragonite and magnetite); Earle M. Floyd, visitor, Colorado, (ferberite, gypsum, aragonite, pyrite, natural coke, leopardite), Arizona, (turquoise), New Mexico, (molybdenite); C. N. Langner exhibited various specimens from a western trip; William Parrish visited Cornwall, Wood's Chrome Mine, and Paterson; Nicola D'Ascenzo, Strickland's Quarry, Conn., (tourmaline, beryl), Westfield, Mass., (datolite, epidote, prehnite, calcite), Blue Ball, Lancaster County, Pa., (dolomite in pink crystals); Harry W. Trudell, Lancaster County, Pa.; Ernest Weidhaas, visitor, Bedford, N.Y., (autunite); Edmund Cienkowski, Amelia, Va., (tantalite, microlite, amazonstone, albite), Statesville, N.C., (quartz, rutile, zircon, corundum), Spruce Pine, N.C., (hyalite, beryl, samarskite, gummite, actinolite, talc, uranophane); Hot Springs, Ark., (quartz crystals), Magnet Cove, Ark., (brookite, eudialyte, rutile, lodestone), at the mercury mines, cinnabar; Tristate area (calcite twins, dolomite, marcasite, galena, enargite); Keokuk, Iowa (geodes); Clay Center, Ohio, (fluorite, calcite, celestite); Morrell Biernbaum, Cornwall, Pa., (magnetite crystals); the secretary exhibited various specimens he had acquired.

Academy of Natural Sciences of Philadelphia, October 4, 1934.

Vice-president Arndt in the chair, with 54 member and 37 visitors present. The present officers were reelected: Dr. Joseph L. Gillson, president; Harold W. Arndt, vice-president; Wylie H. Flack, secretary; Morrell G. Biernbaum, treasurer; and Charles R. Toothaker, councillor.

Dr. William S. Newcomet described a trip, illustrated with lantern slides, taken while traveling through Switzerland, Austria, Poland, and Russia. Details were given regarding the mineral collections seen.

The following trips were reported: Arnold Morris, Thomasville, Pa., (calcite crystals); Nicola D'Ascenzo and Charles R. Toothaker, Bedford, N.Y., (rose quartz, columbite, beryl, gummite, uraninite); Arthur Dornblum, Bedford, (uraninite); John Vanartsdalen, Vanartsdalen's quarry, Bucks County, (graphite in blue quartz); Edmund Cienkowski exhibited specimens from his western trip.

Academy of Natural Sciences of Philadelphia, November 1, 1934.

Vice-president Arndt in the chair, with 46 members and 19 visitors present. Dr. C. W. Rodman addressed the society on "Tungsten, Molybdenum, and Vanadium; Principal Sources, Uses, and Marketing Methods."

The following trips were reported: Alexander Fleming, Jr., Perkiomenville, Pa., (a mass of brown calcite, resembling stilbite); Rady Miller exhibited ferberite from Colorado, and molybdenite from Wilmington, N.Y.

WYLIE H. FLACK, *Secretary*

NEW MINERAL NAMES

Jarlite

RICHARD BØGVAD: New Minerals from Ivigtut, Southwest Greenland. *Meddelelser om Grønland*, 92, No. 8, 1-11, 1933, with 2 plates.

NAME: In honor of Mr. C. F. Jarl.

CHEMICAL PROPERTIES: A fluoride of sodium, strontium and aluminum: $\text{Na Sr}_3\text{Al}_3\text{F}_{16}$. Analysis (by Ragnar Blix): $\text{H}_2\text{O}(-105^\circ)$ 0.08, $\text{H}_2\text{O}(+105^\circ)$ 2.91, F 43.23, Li 0.08, Na 3.23, Mg 0.90, Ca 0.55, Sr 35.60, Ba 0.99, Al 12.16, Fe 0.17; sum 99.90. Soluble in aluminum chloride. B. B. Fuses easily with effervescence and gives an alkaline reaction.

CRYSTALLOGRAPHICAL PROPERTIES: Monoclinic. Forms, a (100), c (001), r ($\bar{1}01$), m (110), b (010). $a:b:c=1.46:1:2.58$. $\beta=69^\circ20'$.

PHYSICAL AND OPTICAL PROPERTIES: Colorless to slightly brownish. Hd. 3-4, $G=3.93$.

Biaxial, negative (may be in part positive?) $\alpha=1.427$, $\beta=1.432-1.433$, $\gamma=1.435$. $2V=78^\circ10'-80^\circ00'$.

OCCURRENCE: In the cryolite quarries at Ivigtut as a dike-like formation with barite, partially dissolved remnants of cryolite and gearsutite (?) and thomsenolite.

W. F. F.

Metajarlite

RICHARD BØGVAD: *Ibid*, pp. 7-11

CHEMICAL PROPERTIES: Like jarlite. Analysis: $\text{H}_2\text{O}(-105^\circ)$ 0.08, $\text{H}_2\text{O}(+105^\circ)$ 2.14, F 45.50, Li 0.04, Na 3.54, Mg 1.38, Ca 3.20, Sr 28.70, Ba 2.25, Al 12.49, Fe 0.31; sum 99.63.

PHYSICAL AND OPTICAL PROPERTIES: Color gray. Hd. 4-4.5, $G=3.780-3.781$.

Biaxial, probably positive. $2V$ near 90° . $n=1.432$.

OCCURRENCE: Found in individuals up to 5 mm. long embedded in chiolite, associated with pyrite, topaz, fluorite and cryolite.

Differentiated from jarlite by its higher content of magnesium, calcium and barium, by its somewhat different optical properties and by its higher specific gravity.

W. F. F.

Igalikite

O. B. BØGGILD: Igalikite and Naujakasite, two new minerals from South Greenland. *Meddelelser om Grønland*, vol. 92, No. 9, 1-7, 1933, with 2 plates.

NAME: From the locality Igaliko, Southwest Greenland.

CHEMICAL PROPERTIES: A hydrous silicate of sodium, potassium and aluminum, $\text{NaKAl}_4\text{Si}_4\text{O}_{15} \cdot 2\text{H}_2\text{O}$. Analysis: (by Chr. Dethlefsen) SiO_2 45.85, Al_2O_3 32.60, Fe_2O_3 0.92, CaO 1.41, MgO 0.15, K_2O 6.29, Na_2O 5.92, H_2O 6.80; sum 99.94. Decomposed by HCl with gelatinization. B. B. Fuses easily (2-3) to a colorless glass.

PHYSICAL AND OPTICAL PROPERTIES: Color light brownish, reddish or grayish. Streak white. Hd. $5\frac{1}{2}$. G 2.559. $n=1.540$ but variable. Birefringence about that of quartz.

OCCURRENCE: Found in a single specimen as the fine grained interior of a rounded mass surrounded by barkevikite, augite, feldspar, and smaller amounts of biotite, magnetite, apatite and olivine.

W. F. F.

Naujakasite

O. B. BØGGILD: *Ibid*, pp. 7-12.

NAME: From the locality Naujakasik.

CHEMICAL PROPERTIES: A hydrous silicate of sodium, iron and aluminum, $\text{H}_2\text{O} \cdot 3(\text{Na}_2, \text{Fe})\text{O} \cdot 2\text{Al}_2\text{O}_3 \cdot 8\text{SiO}_2$. Analysis: (by Chr. Dethlefsen) SiO_2 50.95, Al_2O_3 20.63, Fe_2O_3 2.76, FeO 5.25, Na_2O 14.51, K_2O 0.80, MnO 0.57, CaO 0.55, MgO 0.10, H_2O (100°) 1.02, H_2O (ign.) 2.60; sum 99.74. B. B. Fuses easily (about 3) to a grayish glass. Decomposed by HCl with gelatinization.

CRYSTALLOGRAPHICAL PROPERTIES: Probably monoclinic, pseudo-hexagonal. $a:b:c=1.887:1:2.44$. $a=15.06\text{\AA}$, $b=7.98\text{\AA}$, $c=19.5\text{\AA}$. β moderately inclined from 90° . Cleavage micaceous, perfect.

PHYSICAL AND OPTICAL PROPERTIES: Color silvery white, on cleavage surface, grayish. Luster pearly. Brittle. Hd. 2-3. G. 2.615.

Biaxial. $2V$ near 90° . One optic axis nearly normal to the cleavage. $\beta=1.537$.

OCCURRENCE: Found in a single specimen as an aggregate of mica like plates ranging from 1-3 mm. in diameter. Intimately associated with arvedsonite from Naujakasik, Tunugdliarfik Fjord, SW. Greenland.

W. F. F.

Correction

A redetermination of the indices of refraction of monticellite shows a slight error in the gamma value as given on page 474 of the October 1934 issue of The American Mineralogist. The new values are:

$$\alpha = 1.6463$$

$$\beta = 1.6535$$

$$\gamma = 1.6605$$

$$\text{Birefringence} = .014$$